SPATIAL AND TEMPORAL INFLUENCES OF WATER QUALITY ON ZOOPLANKTON IN LAKE TEXOMA

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Seventy-one aquatic species including the copepodids and nauplii were identified from Lake Texoma from August 1996 to September 1997. Zooplankton community structure, abundance and spatial and temporal distributions were compared among five lake zones delineated *a priori* based on chloride concentration. The zones, in order of decreasing chloride concentration, are the Red River zone (RRZ), Red river Transition zone (RRTZ), Main Lake zone (MLZ), Washita River Transition zone (WRTZ) and Washita River zone (WRZ). Bray Curtis Similarity Index showed community structure was most similar in the two Red River arm zones, the two Washita River arm zones and the MLZ. Zooplankton abundance was greatest in the Red River arm (312 org/L), intermediate in the Washita River arm (217 org/L) and least in the Main Lake body (103 org/L). A significant increase in the abundance of a deformed rotifer, *Keratella cochlearis*, was observed mainly in the Red River arm during a second study from March 1999 to June 1999. Seasonal dynamics, rather than spatial dynamics, were more important in structuring the zooplankton community, especially in the two river arms. Spatial variance was solely attributed to station and zone effects independent of time for a few crustacean species and many of the water quality parameters supporting the presence of longitudinal gradients of differing water quality. Three independent models (Red River arm, Washita

River arm, Main Lake body) rather than a single model for the entire reservoir, best describe patterns in the zooplankton community and its relationship to seasonal, physical and chemical factors. Statistical power, sample size and taxonomic resolution were examined. When monitoring seasonal and annuals trends in abundance, the greatest statistical power was achieved by analyzing count data at taxonomic levels above genus. Taxonomic sufficiency was assessed to determine if costs could be reduced for zooplankton identifications. For water quality monitoring purposes only, it is recommended that genus identifications are sufficient if supplemented with quarterly species identifications.

ACKNOWLEDGMENTS

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This project involved a large number of people at the University of North Texas. First of all I would like to acknowledge my committee, Drs. Dickson, Atkinson, Waller, Beitinger and Acevedo, for their advice, guidance and encouragement during the past five years. Thanks to Gerald Clyde and David Rolbeckie, members of the project team, for their commitment to hard work and persistence in collecting field data and samples. A special thanks is given to Samuel Peacock, Gerald Maschmann, Elizabeth Roberts, and Mark Olsen for their assistance when needed in collecting zooplankton and water quality samples. Thanks to Kenneth Banks for his technical guidance and review of one of the manuscripts.

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INTRODUCTION

Research presented in the following six manuscripts comes from two separate water quality studies conducted on Lake Texoma (Oklahoma, Texas) both funded by the U.S. Army Corps of Engineers, Tulsa District. The primary focus of my research comes from data collected during the 5-year Water Quality Monitoring Program (WQMP). Sampling began in August 1996 and continued through September 1997 for a total of 14 months when funding was stopped. The overall purpose of the WQMP was to develop a baseline of physical, chemical and biological data to assess future changes in water quality in Lake Texoma resulting from the proposed chloride control projects in the Red River watershed. Only first year data (March - November 1999) was used from the second study, a three-year (1999-2001) Water Quality Research Program designed to supplement and compliment the WQMP. The overall purpose of this program is to establish three water quality monitoring stations in Lake Texoma to collect continuous real-time data for pH, temperature, dissolved oxygen, turbidity, conductivity and total fluorescence; evaluate phytoplankton primary productivity; map the spatial distribution of chlorophyll-a and conductivity in the Red River arm and examine intra and inter-annual variability in phytoplankton and zooplankton species abundance. The objectives for my research are 1) to examine the zooplankton abundance and community composition temporally and spatially within the first ten meters of Lake Texoma, 2) examine the relationship between physical-chemical water quality parameters and the distribution of the zooplankton community, and 3) to examine the sensitivity of this sampling

program to detect shifts in zooplankton population density and community composition.

The first four manuscripts analyse spatial and temporal influences of water quality on zooplankton in Lake Texoma. The first manuscript is a description of the zooplankton community structure and seasonal dynamics within the first ten meters of Lake Texoma from August 1996 through September 1997. The second manuscript compares the temporal and spatial variation between the zooplankton community and physical and chemical water quality parameters both among stations and zones. The third manuscript models the relationship between zooplankton species composition, season and the physical-chemical water quality for the whole lake, the Red River arm, the Washita River arm, and main lake body. The fourth manuscript examines the increased observation (during the 1999 study) of aberrant posterior spine formation in the rotifer *Keratella cochlearis* and the environmental conditions present.

The last two manuscripts (5 and 6) analyse the sensitivity of this sampling program to detect shifts in zooplankton population density and taxonomic sufficiency. The fifth manuscript discusses how the power of an analysis changes with respect to sample size and the classification level at which zooplankton are analyzed. The sixth manuscript examines taxonomic sufficiency with regard to Lake Texoma zooplankton and water quality monitoring objectives.

As a whole the manuscripts provide insights into zooplankton spatial and temporal dynamics in lake Texoma and explores the relationship between

chemical and physical water quality parameters and zooplankton distribution in zones of the reservoir.

ZOOPLANKTON COMMUNITY STRUCTURE AND SEASONAL DYNAMICS IN LAKE TEXOMA (OKLAHOMA-TEXAS)

Introduction

Few studies have been published on zooplankton dynamics in Lake Texoma, the majority have concentrated on the Red River arm. Pettitt (1976) examined zooplankton densities and limnological parameters as a part of an intensive whole lake water quality study for a single month, December 1975. According to his study, rotifer and crustacean populations were indicative of eutrophic conditions. Additionally, he reported that zooplankton diversity was greater in the headwaters compared to that of the main lake body.

Crist (1980) observed that zooplankton spatial distributions within three stations in Lake Texoma were heavily influenced by nutrient and salt input from the Red River resulting in dense populations in the Red River arm.

Threlkeld (1982) suggested that the silty inflow from the Red River altered Cladoceran reproduction and individual growth rates, reduced predation from visually oriented predators, influenced vertical and horizontal migration, and influenced the initiation of diapause. Dirnberger and Threlkeld (1986) examined the advective effects of the Red River inflow on zooplankton abundance and dispersion. They concluded that during periods of low inflow from the Red River, zooplankton vertical patchiness was wind induced; however, under strong mixing conditions, zooplankton did not maintain distinct vertical patches and periodic

flooding resulted in a loss of most zooplankton populations within the upper seven meters and deepened the distribution of the remaining individuals.

Work and Gophen (1995) reported on the first occurrence (1991) of *Daphnia lumholtzi* in Lake Texoma. This cyclomorphic species shows large seasonal variation in helmet length and caudal spine length and is larger than other *Daphnia* species in U.S. lakes and reservoirs. Prior to the appearance of *D. lumholtzi*, *D. galeata mendotae* was the largest *Daphnia* species present in Lake Texoma.

In 1996, an intensive five-year water quality monitoring study was begun to update the baseline of physical, chemical and biological data for Lake Texoma. These data can be used to examine the effectiveness of established and future U.S. Army Corps of Engineers chloride control projects aimed at reducing the input of chlorides into the Red River for the benefit of downstream users. Due to lack of funding the study was ended after fourteen months. The purpose of this study is to examine the zooplankton community structure and seasonal dynamics in the first ten meters of the water in Lake Texoma during this fourteen month study period (August 1996 - September 1997). A more comprehensive report can be found in Atkinson and others (1999).

Methods

Lake Texoma is a 36,000-hectare (89,000 acre) multipurpose impoundment with a drainage basin of approximately 103,000 km^2 (39,719 $miles^2$), most of which is pasture and cropland. It occupies portions of both south

central Oklahoma and north central Texas. Major rivers flowing into Lake Texoma are the Red River from the west, which forms the southern border between Oklahoma and Texas and the Washita River from the north. Comparison over a 35-year period (1962 - 1997), annual average discharge in the Red River (3,327 ft^3/s) was approximately twice the discharge in the Washita River (1,882 ft^3/s). River discharges were well within normal values during the study period. At normal pool elevation (617.0 feet), maximum and mean depths are 34 m and approximately 9 m (Atkinson and others 1999).

Lake Texoma was divided into five zones based upon an existing chloride gradient (Atkinson and others 1996), with the greatest chloride concentrations occurring in the Red River zone and least in the Washita River zone. Sampling stations were designated as either routine or intensive. Each zone contained one intensive station and two routine stations. The Red River Transition zone contained one additional routine station in the Big Mineral arm. Three replicate samples were collected from the routine stations and ten replicate samples from the intensive stations from August 1996 through September 1997. One of the routine stations within each zone was a random station whose location was chosen randomly each month from a grid of all possible station locations within a zone with the stipulation that depth was at least six meters. The random stations are not shown in Figure 1 because their location changed among sampling trips. The purpose of the random station was to further characterize the spatial distributions of zooplankton in a zone. The intensive station and second routine

station were fixed locations in the main channel. Sampling frequency was twice monthly for May and June and once monthly for the remaining months skipping October, December and February. Sampling frequency was more relaxed during the winter months and collections were made for November and January only, skipping October, December, and February.

Zooplankton samples (n=1,076) were collected from 16 stations on 13 dates (monthly) from August 1996 through September 1997 (Figure 1). Vertical tows were taken from ten-meters depth to the surface using a No. 20 nylon plankton net fitted with a Wisconsin bucket (80 micron mesh). For stations less than 11 meters in depth, vertical tows were taken from one meter above the bottom to the surface. Station depth was determined using a Hummingbird™ wide-view fish finder. Following collection, the Wisconsin bucket contents were thoroughly washed with distilled water into a prelabeled 125-ml polyethylene sample bottle and preserved with acidified Lugols (Wetzel and Likens 1979). Individual zooplankton sample volumes were adjusted prior to enumeration so that 170 to 200 organisms would be counted from a 1 ml aliquot (EPA 1998). A compound microscope (125X) was used to observe and enumerate zooplankton from a 1 ml aliquot (obtained using a Hensen-Stemple pipette) placed in a Sedwick-rafter counting chamber. Zooplankton were identified to the lowest possible taxon following Edmondson (1959), Stemberger (1979) and Pennak (1989). Counts were converted to organisms per liter of lake water.

Results

Seventy-one species of zooplankton including the cyclopoid and calanoid copepodids and nauplii were identified from collections during August 1996 through September 1997 (Table 1) compared to 28 species for the 1976-77 study (Crist 1980). Species reported in both studies are marked with a single asterisk. Six species were present in the 1976-77 study (**) that were not present in the 1996-97 study. Difference in species richness is probably due to increased sampling effort (72 samples compared to 1,076 samples) and coverage of the reservoir (3 stations compared to 16 stations) in the 1996-97 study. Differences in species present between the two studies occur primarily in the Cladocera (18 species in this study compared to 8 species in previous study) and the Rotifera (38 species this study compared to 10 species in the previous study). Differences in the Cladocera reported are due to the presence of three new genera (*Alona, Chydorus* and *Leydigia*), species identifications for the genera *Ceriodaphnia* and *Moina*, and presence of several new species of *Daphnia* (*D. lumholtzi, D. longiremis, D. pulex, and D. cawtaba*). The presence of *D. lumholtzi* was first noted in 1991 (Work and Gophen, 1995).

Monthly mean (n=82) zooplankton densities ranged from 199.4 org/L in mid-May to 83.9 org/L in mid-June (Figure 2). Seasonal zooplankton densities were lower during the fall and winter months from November through March and during the summer months from mid-June through August. Greatest zooplankton densities occurred during the spring months from April through the first two weeks of June with a second spike occurring in the fall during September.

Mean zonal [n=208 for all zones except the Red River Transition zone (n=247)] zooplankton density was greatest in the Red River arm of Lake Texoma (Red River zone: 161.6 org/L and Red River Transition zone: 150.4 org/L), approximately a third greater than that of the Main Lake body (103.0 org/L), Washita River Transition zone (113.0 org/L and Washita River zone (104.4 org/L)(Figure 3). Nauplii and calanoid copepod densities decreased from zone to zone from the Red River zone (47.3 org/L and 11.4 org/L, respectively) on through the Washita River zone (29.1 org/L and 6.9 org/L, respectively). Cyclopoid copepod densities were greatest in the Red River arm and Main Lake body (14.5 org/L and 15.1 org/L, respectively) and least in the Washita River arm (Washita River Transition zone: 10.5 org/L and Washita River zone: 6.5 org/L. Rotifer densities showed a decreasing trend from the upper arms of the Red River (67.5 org/L) and Washita River (51.2 org/L) to the Main Lake body (21.9 org/L). Cladocera densities were greatest in the Red River arm (20.9 org/L and 30.5 org/L) and decreased steadily from the Main Lake body (17.2 org/L) on through the Washita River zone (10.9 org/L).

Percent composition of the major zooplankton groups within a zone was similar among zones (Figure 4). Rotifers were the dominant group followed (in decreasing density) by the nauplii, cladocera, cyclopoid copepods and calanoid copepods. This same pattern was observed in the Red River Transition zone and Main Lake body, except that the nauplii density was greater than the rotifer density.

Bray-Curtis Similarity Index analyses at the genus level revealed three patterns of similarity of species composition between zones during the study (Figure 5). The Red River zone and Red River Transition zone formed one group. A second group included the Washita River zone and Washita River Transition zone. The Main Lake body was separate, but more similar to the Red River arm than the Washita River arm. This outcome fully supports reservoir zonation (Thornton and others, 1982).

A common species is arbitrarily defined as species present in ≥ 10% of the samples (n=1076). Those species omitted from the analysis are not necessarily unimportant, but often were littorial species that may have drifted on the currents into the limentic regions of the lake. Examples from the Crustacea include *Chydorus sp., Alona* sp., *Moina spp*. and *Leydigia spp*.. Examples from the Rotifera include *Weigrella depressa* and *Trichotria tetractis*. Of the Crustacea species, 55% of the cladocera, 87.5% of the cyclopoid copepods and 80% of the calanoid copepod species were considered common. Forty-three percent of the Rotifera species were considered common.

Cladocera abundance was greatest from April through May and then declined sharply in July (Figure 6). *Daphnia* exhibited the greatest density of the cladocerans (54.0 to1.5 org/L) followed by *Bosmina (*22.8 to 0.3 org/L), *Ceriodaphnia* (8.1 to 0.2 org/L) and *Diaphanosoma* (4.6 to 0.2 org/L*). Daphnia lumholtzi* populations increased during the summer months when other daphnids experienced a sharp decline. Work (1997) and Work and Gophen (1995)

reported similar observations in Lake Texoma. Cladoceran abundance showed a decrease in August and September 1997 compared to August and September of the previous year.

Nauplii abundance greatly exceeded the abundance of both the calanoid and cyclopoid copepods except for the months of August and November 1996 and July 1997 (Figure 7). Cyclopoid copepod abundance was generally greater than calanoid copepod abundance. Of the two calanoid copepod genera, *Diaptomus* abundances exceeded *Eurytemora* abundances for the periods August through November 1996 and mid-May through mid-June 1997 (Figure 8). Calanoid copepodite abundance generally exceeded that of the adults except during the latter part of the study. Of the cyclopoid copepod genera, *Mesocyclops* was generally present in greater densities than *Cyclops* and *Acanthocyclops* (Figure 9). The cyclopoid copepodites exhibited the greatest abundances (5.1 to 0.9 org/L) of the cyclopoid group.

The ratio of calanoid:cyclopoid copepods plus cladoceran species was first used as a measure of trophic condition in the Great Lakes (Gannon and Stemberger 1978). Calanoid copepods are considered best adapted to oligotrophic waters, while cyclopoid copepods and cladocerans are generally more abundant in eutrophic waters; therefore, the higher the value the less eutrophic the water. Since Lake Texoma is a river-run system with input from two rivers, one would expect the index value to be greater in the deeper, less turbid lake-like portion of the reservoir; however, just the opposite was observed.

Index values ranged from 1.15 to 0.01 (n=940); the greatest values occurring at stations in the Red River zone, Washita River Transition zone and Washita River zone. The index value was less than 1.0 in 99.8% of the samples. The Washita River zone, Washita River Transition zone, and Red River zone have the greatest mean values (0.41, 0.34, and 0.33, respectively) and the Red River Transition zone and Main Lake body have the lowest mean values (0.24 each) (Figure 10). The zooplankton index ratio is highly significantly different among the five zones (one-way ANOVA, F= 18.29, p= 0.0001). A Tukey's multiple comparison test (alpha = 0.10) separated the five zones into three statistically different groups: Washita River zone ($\bar{x}$ =0.41) > Washita River Transition zone ($\bar{x}$ =0.34) and Red River zone ($\bar{x}$ =0.33) > Main Lake body ($\bar{x}$ =0.24) and Red River Transition zone ($\bar{x}$ =0.24). Based upon this index, Lake Texoma is a eutrophic reservoir. Based upon Secchi depth and chlorophyll-a trophic state index values during the same period, Lake Texoma would be classified as eutrophic during months of high productivity and as mesotrophic from November through May (Gibbs, 1998).

Brachionus and *Keratella* exhibited the greatest abundances of the rotifer genera (Figure 11). *Brachionus* abundance exceeded the abundance of the other rotifer genera in 10 out of 13 sampling trips or 77% of the time and likewise, *Keratella* abundance was greater in 7 out of 13 sampling trips or 54% of the time. Of the remaining Rotifera genera, *Synchaeta* and *Polyarthra* exhibited the most dynamic abundances (Figure 12). *Asplanchna* and *Trichocera* abundances

were fairly constant during the study until the summer months from mid-June through July. Brachionus, Keratella, *Polyarthra* and *Trichocera* are rotifer genera indicative of eutrophic conditions (Gannon and Stemberger 1978).

Monthly mean Shannon species diversity values for the entire study ranged from a high of 3.5 occurring in September 1996 in the Washita River zone to a low of 1.6 occurring in mid-June in the Main Lake body (Figure 13). Species diversity values of 3.0 or greater occurred most often in the Washita River zone (46% of the sampling trips), followed by the Red River Transition zone (23%), the Washita River Transition zone (15%) and the Red River zone and Main Lake body (both 8%). Species diversity values dropped below 2.0 on two occasions in the Main Lake body.

Monthly mean species evenness values for the entire study ranged from a high of 0.8 occurring in September 1996 and July 1997 in the Washita River zone and mid-May 1997 in the Washita River zone and Red River Transition zone to a low of 0.5 occurring in August 1997 in the Main Lake body.

Trends in mean monthly Shannon species evenness were similar to those trends for Shannon species diversity. Evenness values followed the same general pattern between the Red River zone and Red River Transition zone and between the Washita River zone and Washita River Transition zone. Like the mean Shannon species diversity values for the Main Lake body, the mean Shannon species evenness values were fairly stable from August 1996 through May 1997 and then began to fluctuate erratically for the remainder of the study.

Discussion

Lake Texoma has a diverse zooplankton community represented by 71 species of zooplankton (Table 1). Crist (1980) reported 28 zooplankton species in the 1976-77 study, which is considerably less than found in this study. Differences in reported species primarily occur in the Cladocera and the Rotifera. A primary reason for differences in species identified between the two studies is due to the increased sampling intensity in the current study (n=1076) and increased coverage of the main channel of the reservoir (16 stations). The three sampling sites from the 1977-76 study were included in the current study. A total of 6 samples were collected for each sampling trip in 1977-76 study compared to 82 samples for the current study.

Total zooplankton abundance followed a typical seasonal pattern represented by a major pulse in the spring (May and June) and a second smaller pulse in the fall (September) when the zooplankton population recovered from the summer crash. Similar population dynamics have been reported for Lake Texoma (Crist 1980, Threlkeld 1982, Matthews 1985, Dirnberger and Threlkeld 1986, and Work 1997) and other reservoirs (Threlkeld 1985).

Overall, monthly zooplankton densities were much greater in the Red River arm, intermediate in the Washita River arm and lowest in the Main Lake body. This observation is in agreement with the 1976-78 study of seasonal and spatial variability of zooplankton in Lake Texoma (Crist 1980). Exceptions to this trend were found in March and mid-June 1997 when the greatest abundance

occurred in the Main Lake body. This same trend was evident in the major groups of zooplankton except the deviations from this trend occurred in different months. Cladocera densities were generally lower in the Main Lake body than either the Red River arm or Washita River arm except for March, mid-June and August 1997. Cyclopoid copepod densities were typically greater in the Red River arm except for March when they were considerably greater in the Main Lake body and mid-June when they were greatest in the Washita River arm. Nauplii densities were typically greatest in the Red River arm, intermediate in the Washita River arm and lowest in the Main Lake body. Rotifera densities were typically lowest in the Main Lake body except for March. Calanoid copepod densities did not seem to follow any particular trend with regard to zonal abundance between months.

Shannon species diversity was greatest in the Red River arm and Washita River arm and lowest in the Main Lake body. There was only a fraction of a difference between zonal species diversity index values for any given month suggesting no ecological difference in community structure with regard to water quality between zones. Differences in species diversity index values between months are also small and do not indicate ecological differences in community structure associated with water quality on an annual basis. Therefore, because this index is not effective in detecting differences in community structure between zones in Lake Texoma, it will probably best serve as a baseline value to which future studies can be compared.

Species evenness describes how evenly distributed the individuals are among the different species. It is the ratio of species diversity (H) to the maximum species diversity (H_{max}). Values range from 0 to 1, where 1 is the maximum species diversity in which all species in the community would have an equal number of individuals. In Lake Texoma, species evenness ranged from 0.5 to 0.8, but monthly differences between zones were small. Evenness, is therefore, best used as a baseline value to which future studies can be compared.

Species richness is simply an inventory of the number of different species observed during each sampling trip. Species richness was generally greatest in the Red River and Washita River arms and least in the Main Lake body. This observation is consistent with the nature of reservoirs and the longitudinal gradients that form as water flows from the mouth of the major tributary to the main lake basin (Thornton and others 1982). Flowing water typically has a higher sediment load, greater turbidity and increased nutrients which favors a higher plankton species richness. As the water flows towards the dam, sediments settle out and it becomes less turbid and lower in nutrients supporting fewer species. Also, as the water flows from the mouth of the tributary to the dam, it becomes increasingly deeper which also has an effect on plankton species richness favoring more species in shallower water as compared to deeper water.

Bray-Curtis Similarity Index analyses revealed three patterns of similarity of species composition between zones during the study period. Species composition was similar between the Red River and Red River Transition zone and the Washita River and Washita River Transition with the Main Lake body being separate, but most similar to the Red River arm.

The calanoid:cyclopoid plus cladoceran ratio is specifically applicable for detecting differences in trophic status among water masses of differing eutrophy in the Laurentian Great Lakes (Stemberger and Gannon 1978), however, care must be taken to use it elsewhere. Although statistically significant differences in trophic status were found among zones using this index, its application to Lake Texoma may not necessarily be related to differences in trophic status among zones but more to differences in water quality due to other issues.

In summary, the seasonal patterns in the zooplankton density of Lake Texoma are typical of those found in temperate reservoirs in which densities peak in the spring, decline sharply during the summer months, and then peak again in the fall. As in a previous study, greatest densities were found in the Red River arm, intermediate densities in the Main Lake body, and lowest densities in the Washita River arm. Mean densities for several species showed a decline during the second year in August and September.

Zooplankton species composition was typical of that for a river-run system with species richness being greatest in the headwaters and transition zone and least in the deeper main lake body. Species composition and richness was

generally most similar between the Red River arm zones and Washita River arm zones and different from the Main Lake body. Considerably fewer species, especially rotifers, were found in the deeper Main Lake body.

Lake Texoma can be classified as eutrophic based upon the presence of eutrophic indicator species such as the rotifers, *Brachionus*, *Keratella*, *Polyarthra*, *Trichocera* and the cladocera, *Bosmina longirostris*. These species were often dominant throughout the study. Another index, the ratio of calanoid to cyclopoid copepods plus cladoceran species, also classified Lake Texoma as eutrophic.

Table 1 Zooplankton species of Lake Texoma identified in the 1977-76 study (*) and 1996-97 study. Species unique to the 1977-76 study are marked with a double asterisk (**).

CLADOCERANS	ROTIFERS
Alona costata	*Ascomorpha sp.*
A. rectangula	*Asplanchna sp. *
*Bosmina coregoni **	*Brachionus angularis *
B. longirostris	*B. bidentata*
*Ceriodaphnia sp. *	*B. budapestinensis*
C. quadrangula	*B. calyciflorus *
C. reticulata	*B. caudatus*
Chydorus sphaericus	*B. havanaensis*
*Daphnia ambigua *	*B. quadridentatus*
D. cawtaba	*B. rubens*
*D. galaeta mendotae *	*B. urceolaris*
D. longiremis	*B. varibilis *
D. lumholtzi	*Collotheca sp.*
*D. parvula *	*Conochiloides dossarius*
D. pulex	*Euchlanis alta*
*Diaphanosoma bergei *	*Filinia longiseta*
*Leptodora kindtii *	*F. terminalis *
Leydigia acanthocercoides	*Gastropus sp.*
*Moina sp. *	*Hexarthra mira*
Moina brachiata	*Kellicottia bostoniensis*
M. micrura	*Keratella americana **
	K. cochlearis
COEPEODS	*K. quadrata f. testudo *
Calanoid Coepeods	*Lecane luna*
Calanoid copepodid	*Lepadella patella*
Diaptomus connexus	*Monostyla stenroosi*
*D. doraslis **	*Notholca acuminata*
*D. silicoides **	*N. strata **
D. saltillinis	*Platyias patulus*
Eurytemora affinis	*P. quadricornis*
Cyclopoid Copepods	*Polyarthra sp. *
Cyclopoid copepodid	*P. dolichoptera*
*Acanthocyclops vernalis *	*P. euryptera*
*Cyclops bicuspidatus *	*Pompholyx sp.*
Ectocyclops phaleratus	*Porales sp.*
*Ergasilus versicolor *	*Synchaeta sp.*
*Mesocyclops edax *	*Testudinella sp.*
*M. inversus *	*Trichocera lata*
*Tropocyclops prasinus mexicanus **	*T. multicrinis*
Harpacticoid copepods	*T. similis*
Harpacticoid sp.	*Trichotria tetractis*
copepod nauplii	*Wigrella depressa*

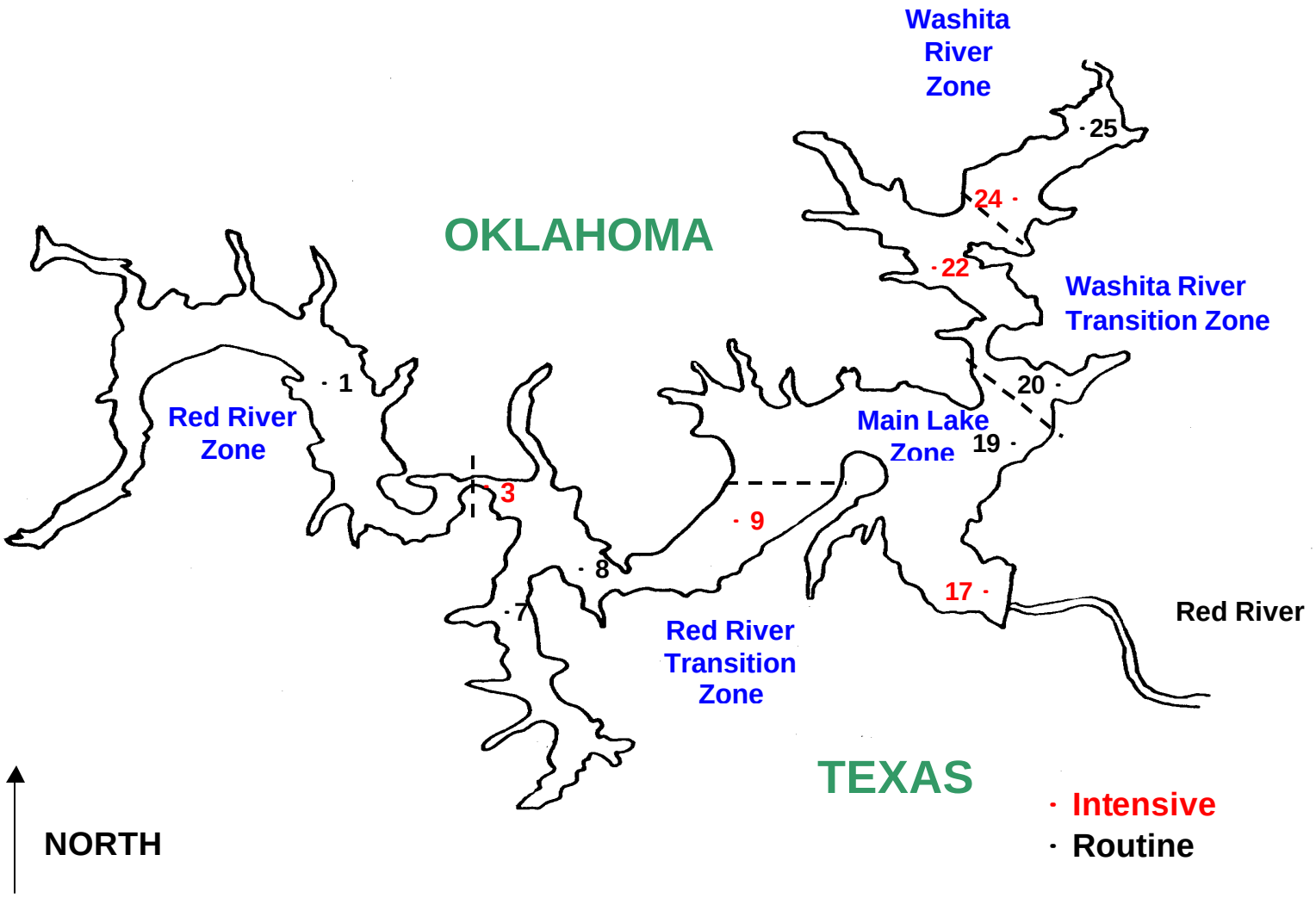

Figure 1 Map of Lake Texoma showing routine and intensive fixed station locations with each zone.

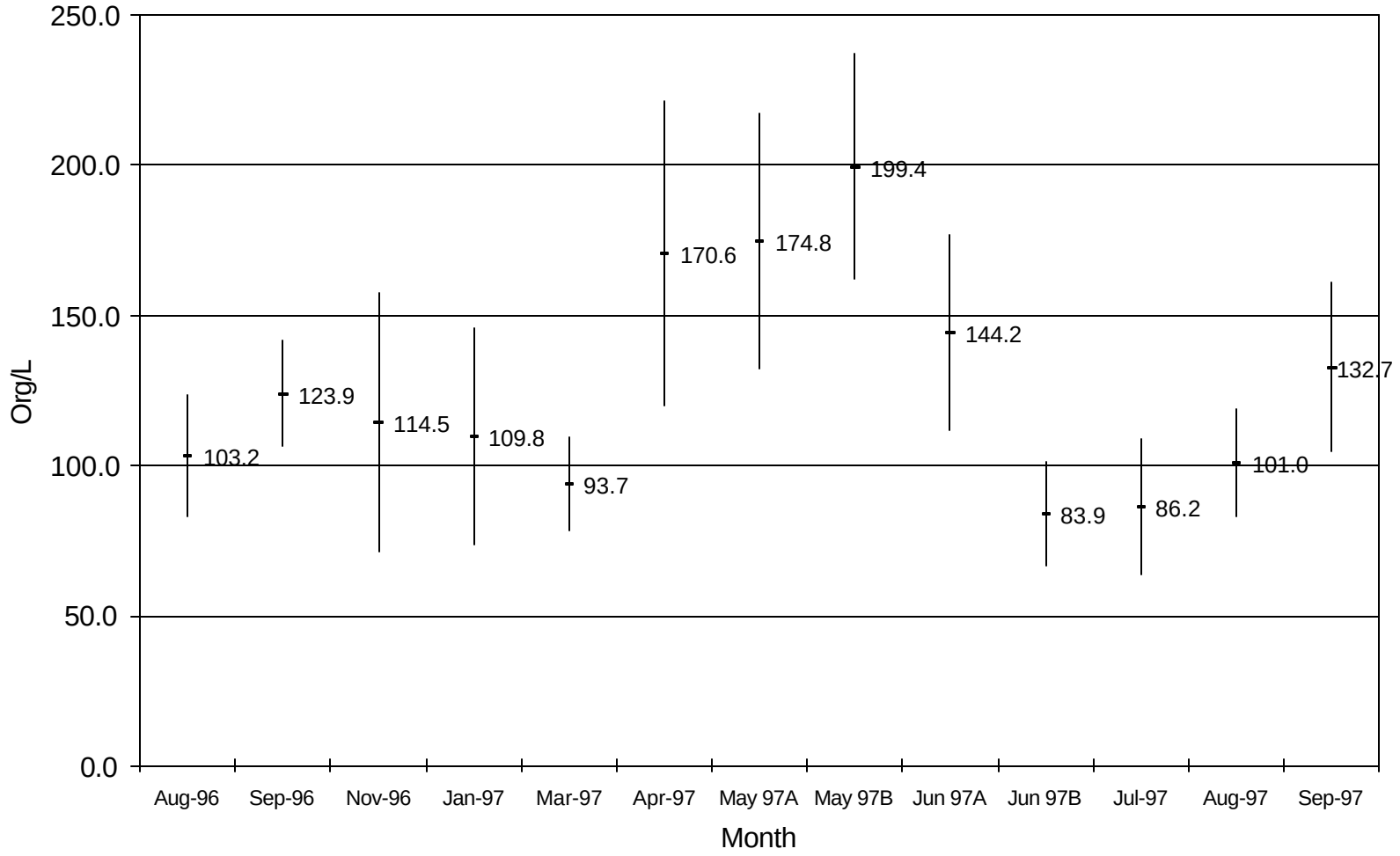

Figure 2 Seasonal zooplankton abundance (mean and 90% confidence interval, n = 82 per month)

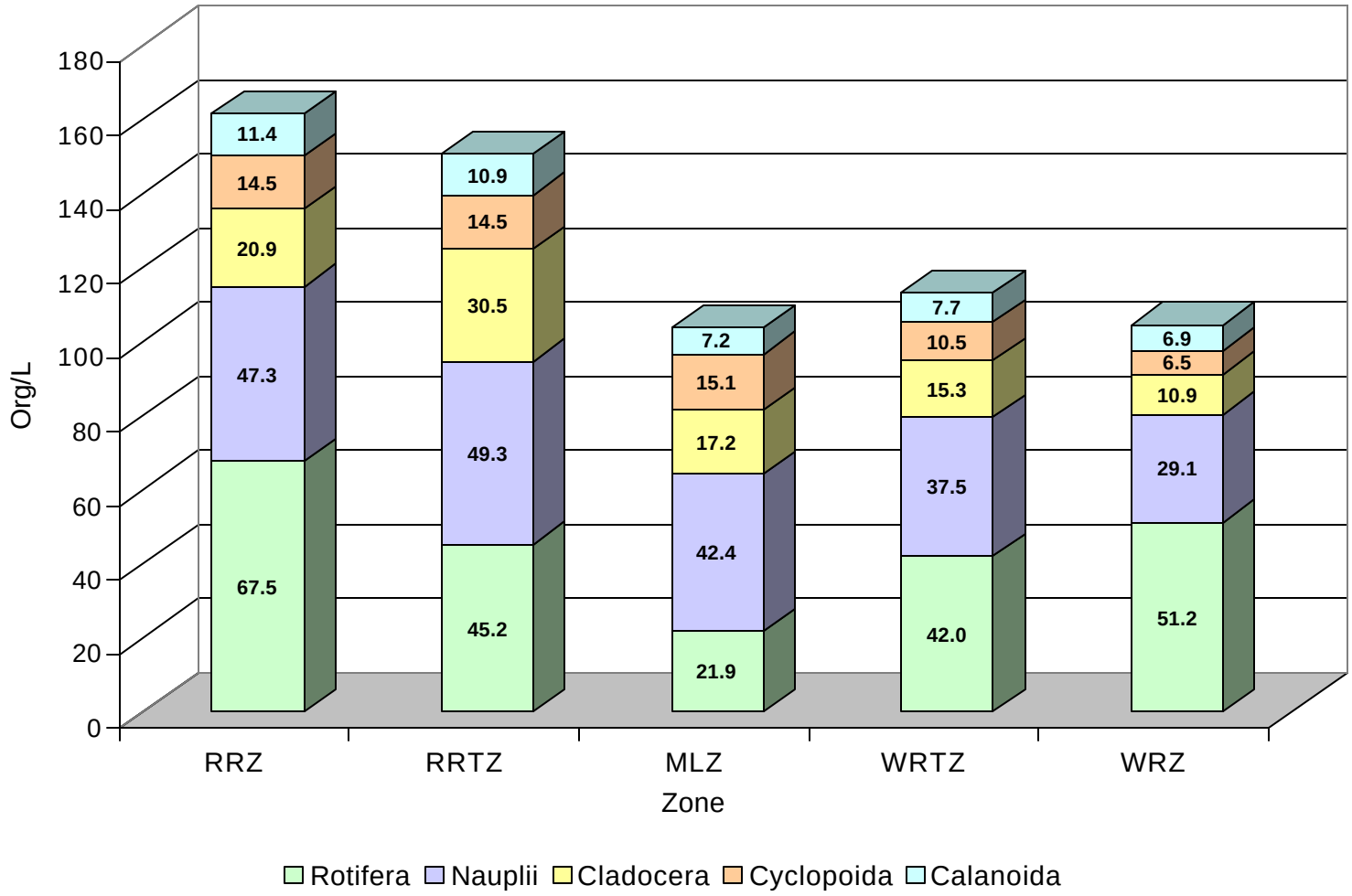

Figure 3 Grand mean density (org/L) for major zooplankton groups by zone.

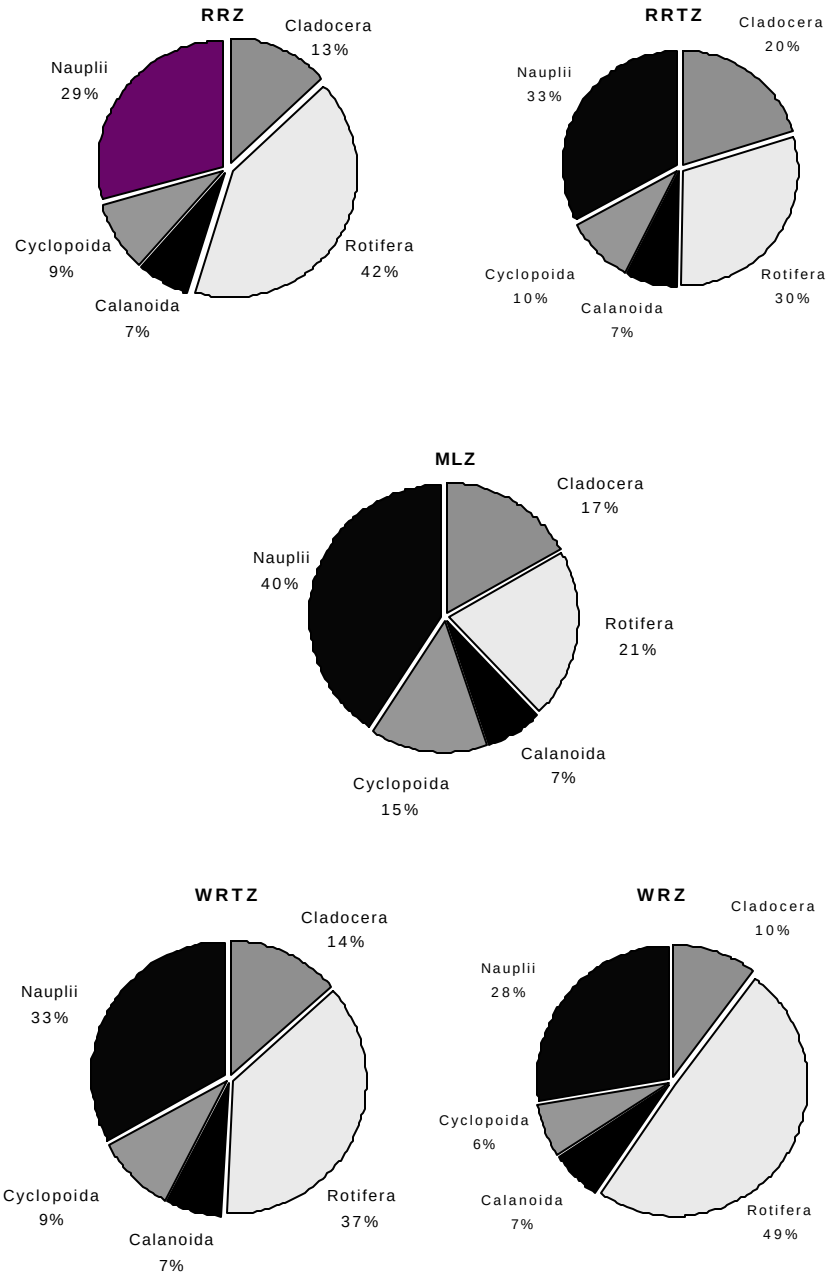

Figure 4 Percent composition of major zooplankton groups within each zone for August 1996 through September 1997. RRZ = Red River zone, RRTZ = Red River Transition zone, MLZ = Main Lake body, WRTZ = Washita River Transition zone, WRZ = Washita River zone.

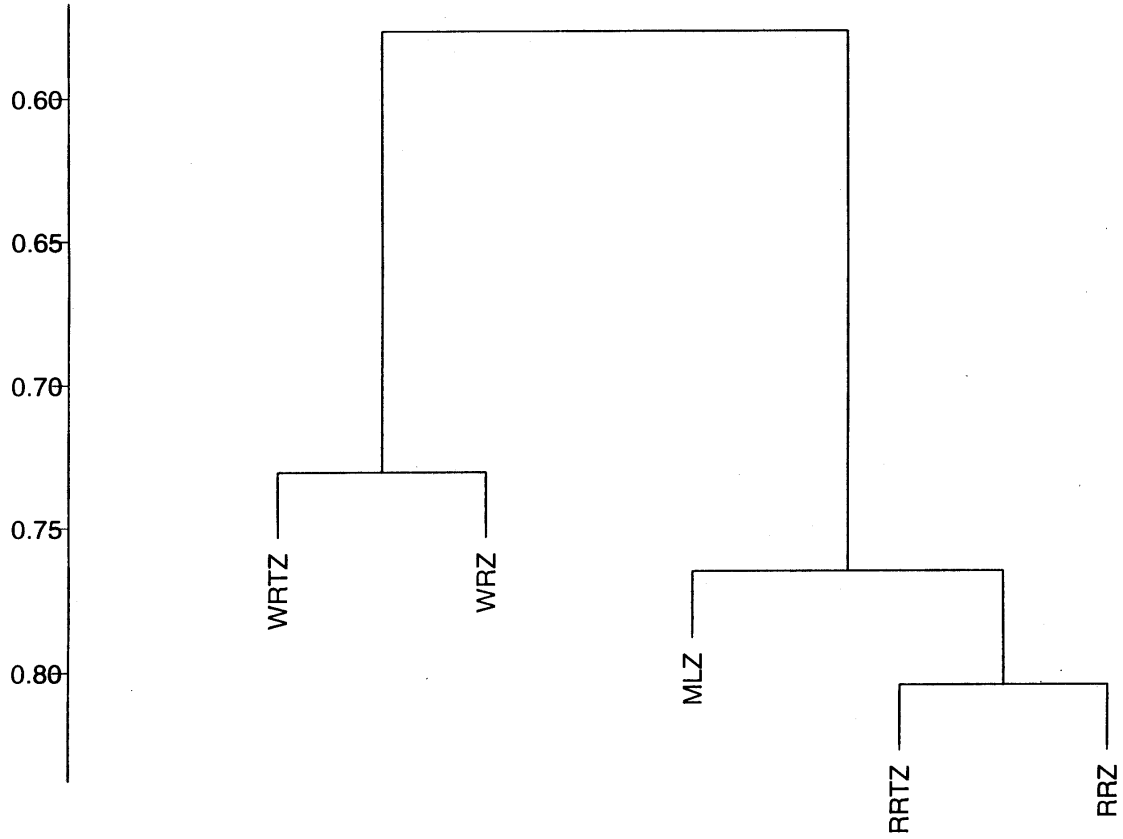

Figure 5 Bray Curtis diagram combining all zones and dates. RRZ = Red River Zone, RRTZ = Red River Transition zone, MLZ = Main Lake Body, WRTZ = Washita River Transition zone, and WRZ = Washita River zone.

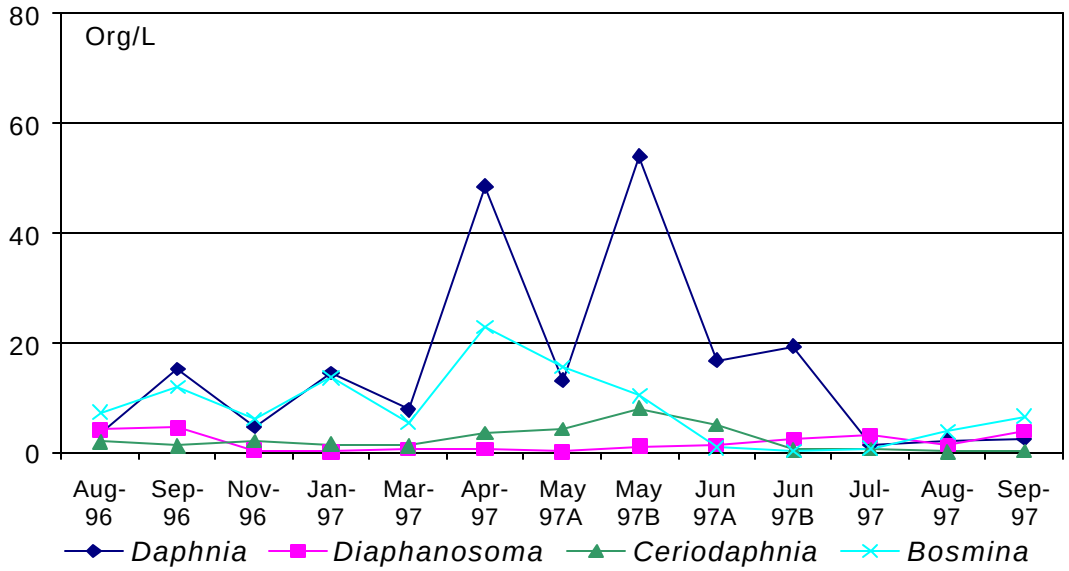

Figure 6 Trends in cladoceran mean abundance (org/L) from August 1996 to September 1997 for the genera *Bosmina, Ceriodaphnia, Daphnia* and *Diaphanosoma.*

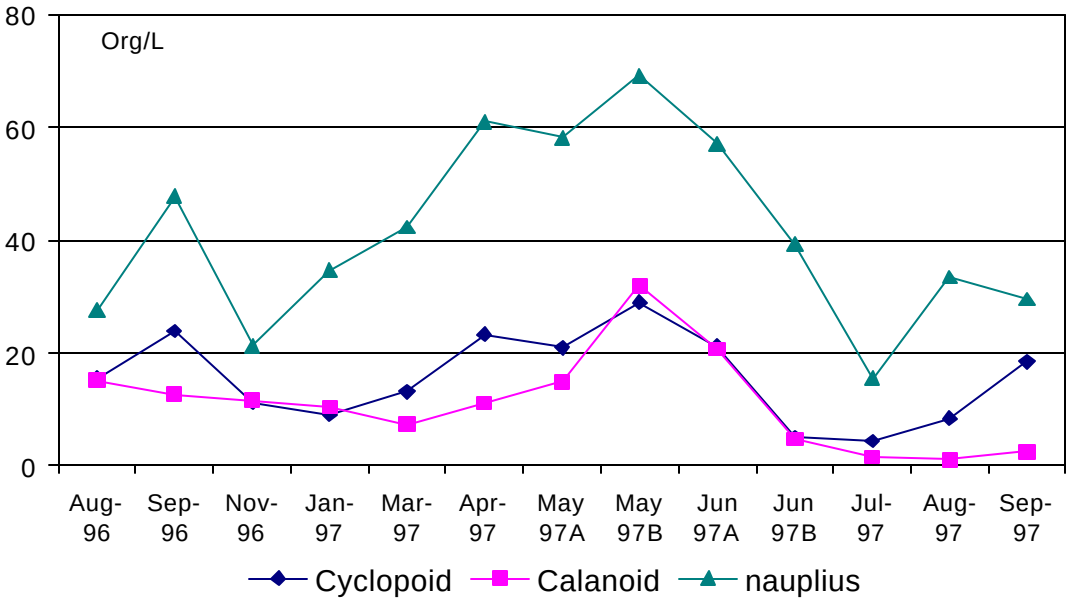

Figure 7 Trends in copepod mean abundance (org/L) from August 1996 to September 1997.

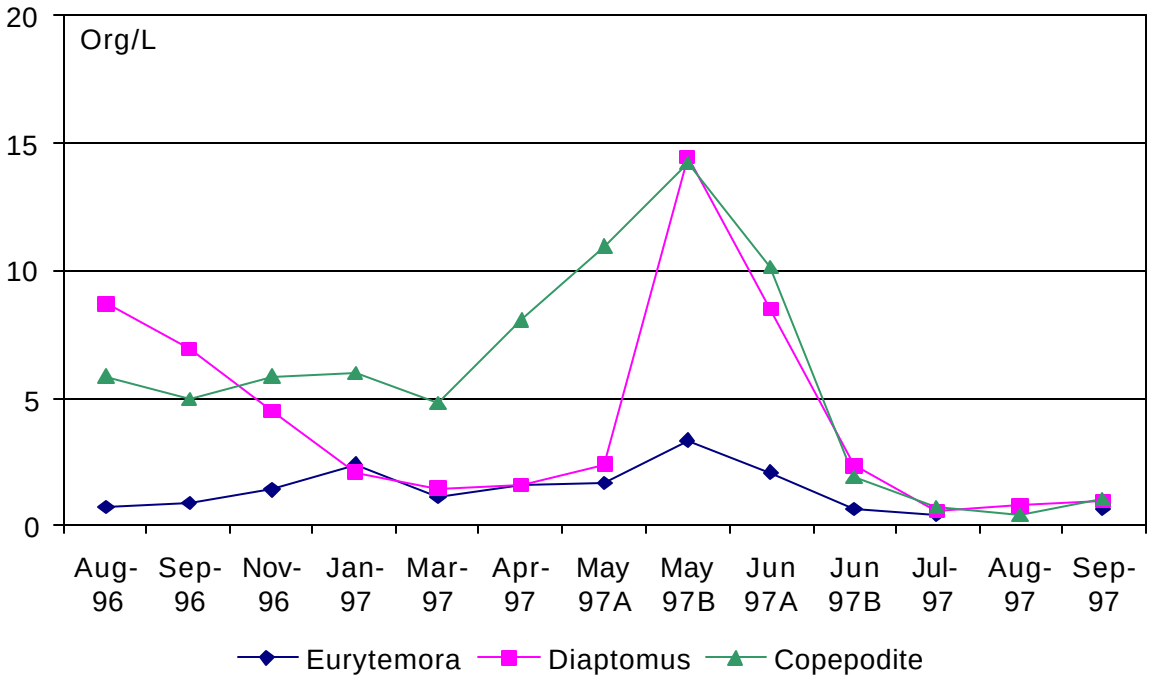

Figure 8 Trends in calanoid copepod mean abundance (org/L) from August 1996 through September 1997 for the genera *Diaptomus, Eurytemora*, and the copepodites.

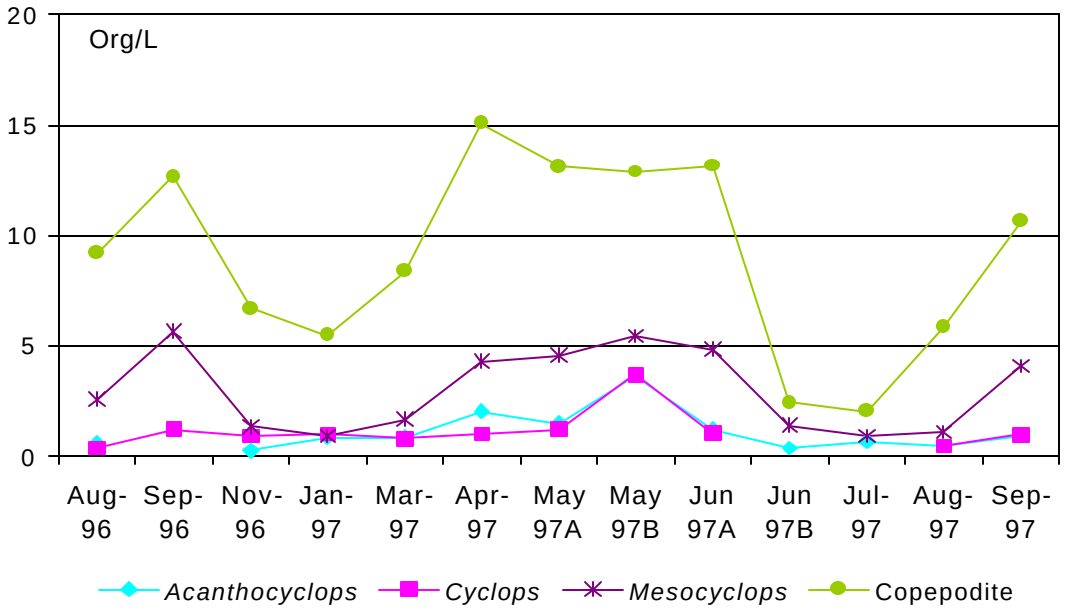

Figure 9 Trends in cyclopoid copepod mean abundance (org/L) from August 1996 through September 1997 for the genera *Acanthycyclops, Cyclops*, *Mesocyclops* and the copepodites.

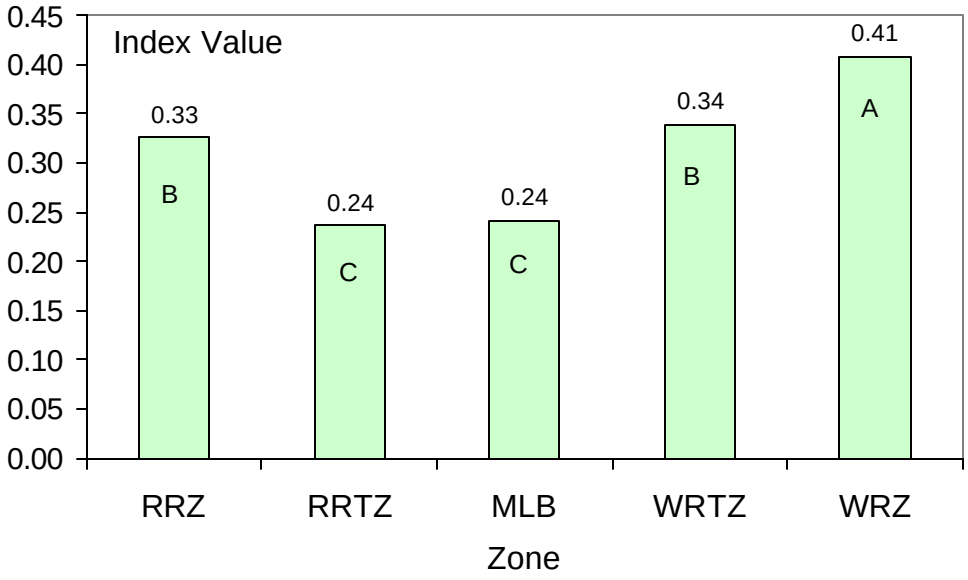

Figure 10 Zooplankton index averages among zones from August 1996 through September 1997. Zones with the same letter are not statistically significantly different (alpha = 0.10).

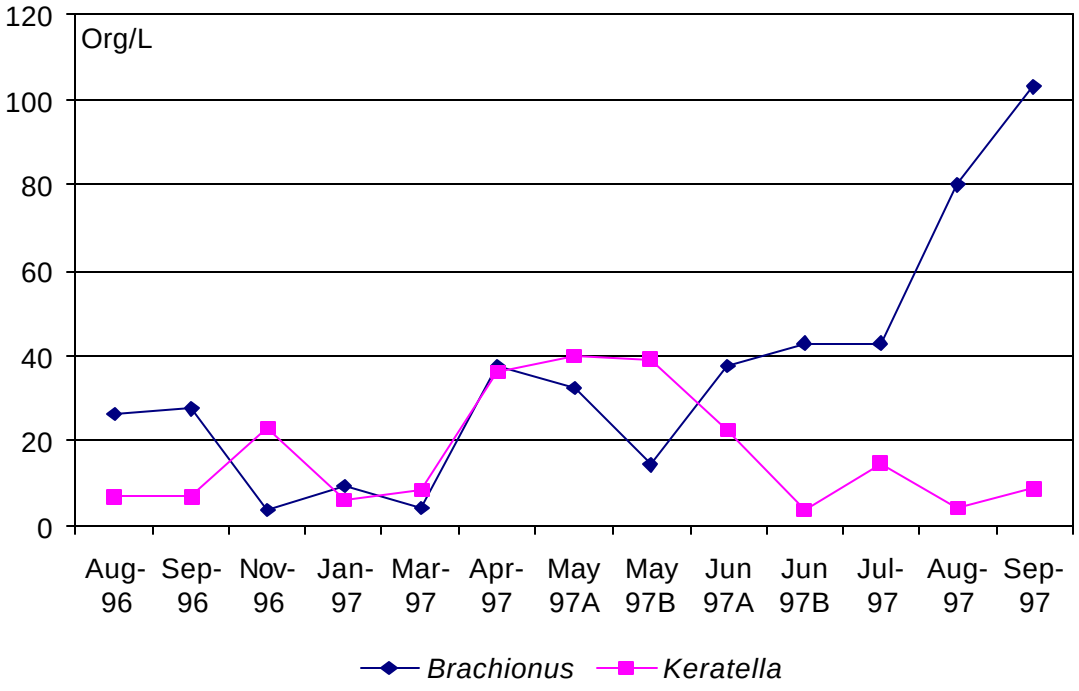

Figure 11 Trends in rotifer mean abundance (org/L) from August 1996 through September 1997 for the genera *Brachionus* and *Keratella*.

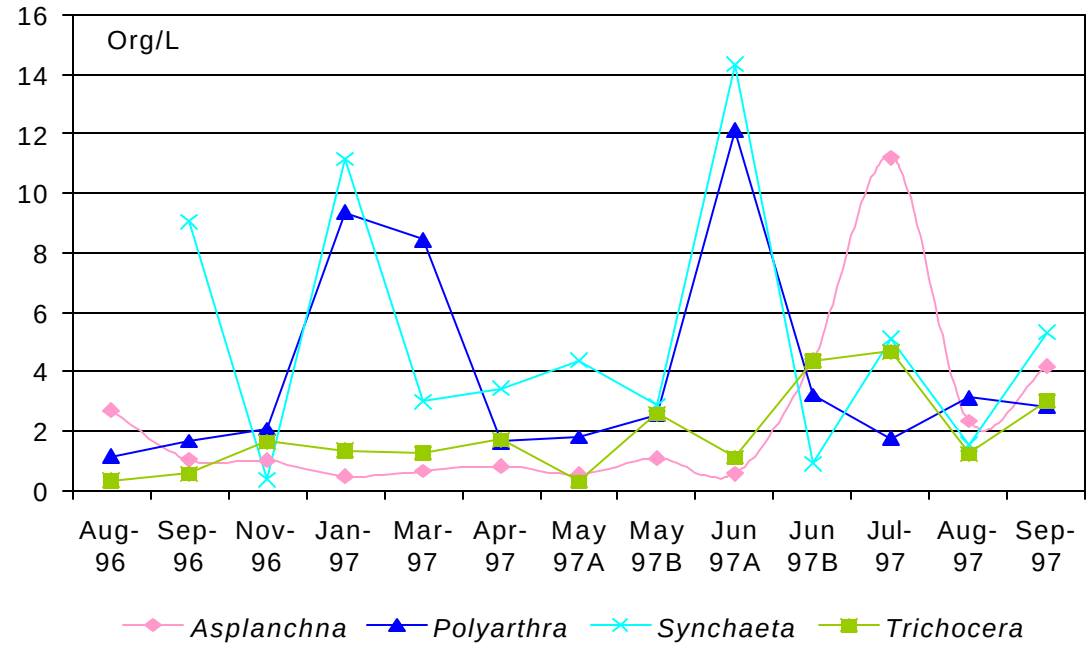

Figure 12 Trends in rotifer mean abundance (org/L) from August 1996 through September 1997 for the genera *Asplanchna, Polyarthra, Synchaeta* and *Trichocera*.

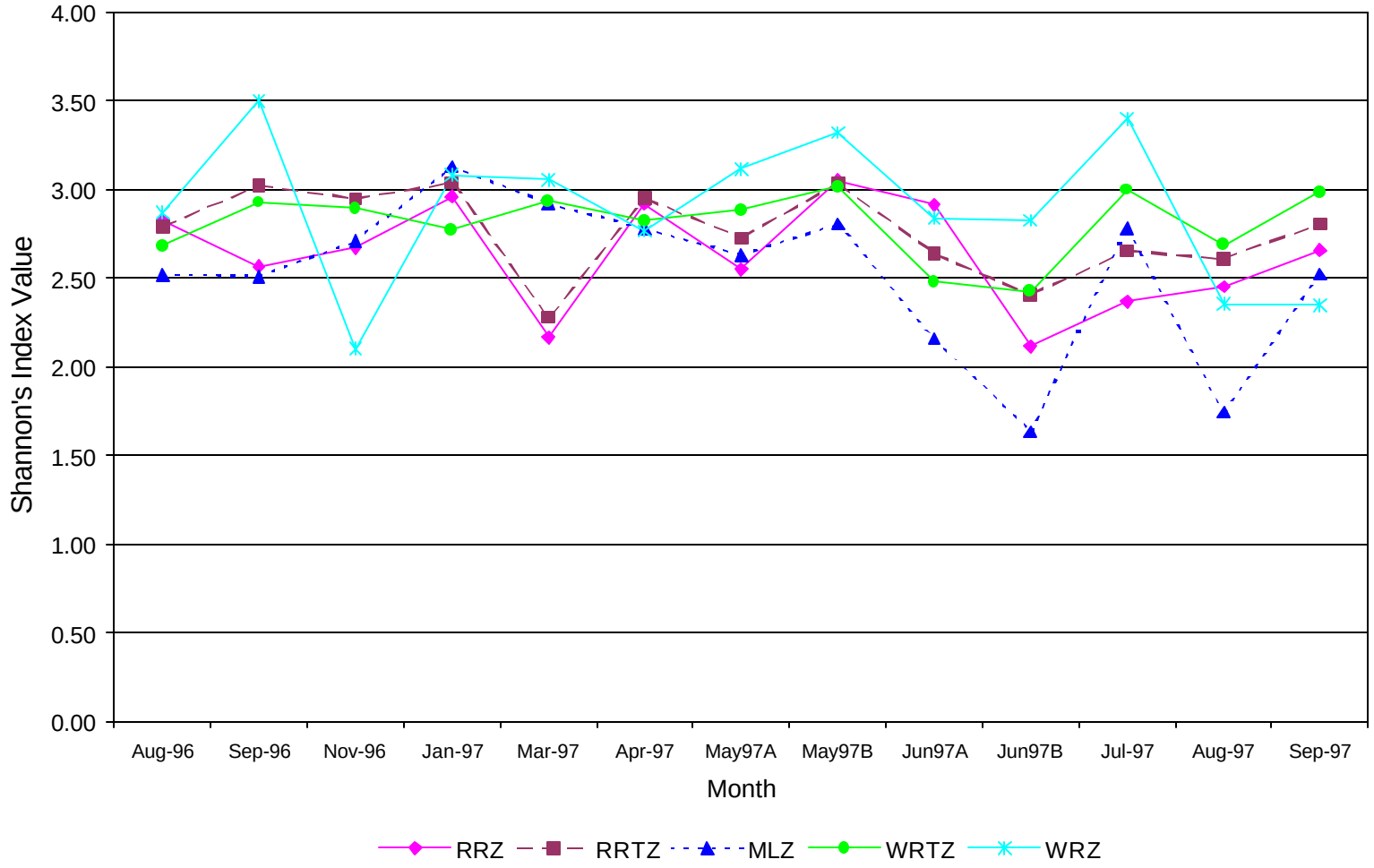

Figure 13 Shannon species diversity by zone for August 1996 through September 1997.

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COMPARISON OF TEMPORAL AND SPATIAL VARIATION IN THE ZOOPLANKTON COMMUNITY AND PHYSICAL AND CHEMICAL PARAMETERS IN LAKE TEXOMA

Introduction

Lewis (1978) hypothesized that systems with dominant fixed spatial gradients should also have dominant fixed spatial components of variance in their zooplankton communities. To test this hypothesis, he proposed a method to examine the temporal and spatial variation in zooplankton in tropical Lake Lanao (Philippines) using spatial and temporal variance components. The temporal component describes variance through time. The spatial component was separated into an ephemeral spatial or station-time interaction component and a horizontal fixed spatial or station effect component. The fourth component describes the variance in error. Results showed that for Lake Lanao, spatial variation exceeded temporal variation in about half the species and ephemeral spatial variation was more important in the structuring of lacustrine zooplankton communities than the fixed (station) spatial variation. Therefore, station-time interactions rather than fixed station effects alone had a greater influence on the zooplankton community. Conflicting results were reported in a similar study on Normandy Reservoir in south central Tennessee (Threlkeld 1983). Again ephemeral variation in the zooplankton was greater than fixed, but unlike Lake Lanao, pronounced gradients in water quality were present along the longitudinal

axis of Normandy Reservoir. This outcome was in direct conflict with that of Lake Lanao because both the zooplankton community and water quality characteristics did not exhibit dominant fixed station effects. The conflicting results are most likely due to differences in study length. The Lake Normandy study considered only the summer zooplankton community (5 dates over 3 months), whereas, the Lake Lanao study included the spring and summer zooplankton community (5 dates over 6 months).

Like Normandy Reservoir, Lake Texoma exhibits fairly stable permanent physical and chemical gradients along the axes of its arms. If Lewis' hypothesis is correct, both the zooplankton and water quality characteristics will exhibit dominant fixed spatial components. The purpose of this research is to examine the temporal and spatial variation in zooplankton abundance and the physical and chemical variables in Lake Texoma for 11 dates over 14 months as described by Lewis (1978) to test if his hypothesis is supported. The analysis will be performed using station data and also zone data (stations combined within a defined zone) to determine if the same patterns hold between station and lake zones.

Methods

Zooplankton and water samples were collected from 16 stations on Lake Texoma, a multipurpose reservoir located on the Red River between Texas and Oklahoma, from August 1996 through September 1997 (Figure 1). Six sampling stations were classified as routine stations (1, 7, 8, 19, 20,and 25) and 5 as

random stations from which 3 replicate samples were collected. Five stations were classified as intensive stations (3, 9, 17, 22 and 24) from which 10 replicate zooplankton and water samples for turbidity and chlorophyll-a analysis were collected. Samples were collected monthly except as follows: 1) samples were not collected for the months of October and December 1996 and February 1997 because historical data shows little change in physical-chemical parameters during the winter months (Atkinson and others 1996), and 2) samples were collected twice monthly for May and June when physical-chemical and biological changes were most dynamic.

Zooplankton samples were collected by a ten-meter vertical tow using a No. 20 nylon plankton net fitted with a Wisconsin bucket (80 micron mesh) for concentrating samples in the field. For stations less than 11 meters deep, vertical tows were taken one meter off the bottom. Station depth was determined using sonar. Contents of the Wisconsin bucket were thoroughly washed with distilled water into a prelabeled 125 ml polyethylene sample collection jar and preserved with Lugols solution (Wetzel and Likens, 1979). Zooplankton were enumerated and identified to the lowest possible taxon following Edmondson (1959), Stemberger (1979) and Pennak (1989). A minimum of 170 to 200 organisms were counted per sample (EPA 1998). Counts were converted to organisms per liter of lake water.

Temperature (^{o}C), dissolved oxygen (mg/L), conductivity (µS/cm) and pH (standard units) were measured with a Hydrolab (H20) datasonde at two meter

intervals beginning one meter below the surface and ending one meter above the bottom. Data collected for the first nine meters of the water column was used in this analysis because this is the portion of the water column where zooplankton were collected. Triplicate secchi depth measurements were taken following Lind (1985).

Water samples were pumped from one meter below the surface for 16 water chemistry analyses listed in Table 2. TRAC Laboratories, Denton, Texas completed the analyses including chlorophyll-a for August 1996 and September 1996 samples. Beginning with the November 1996 samples, chlorophyll-a analyses were performed at the University of North Texas. Analytical methods employed were based on EPA guidelines and standards adapted from APHA 1986.

Statistical Analyses

A standard two-way analysis of variance was used to separate spatial and temporal variation and their interaction at station and zone levels in zooplankton abundance and physical chemical data using SAS (Version 6.12). Variance components (station, month, interaction, and error) were expressed as a percentage of the total variance. Variance ratios were calculated from the variance percentages to describe the proportion of monthly variance accounted for by fixed spatial differences and ephemeral spatial differences. The fixed spatial component, as described by Lewis (1978), is associated with predictable unevenness between stations independent of date. The ephemeral spatial

component is associated with turbulence and water movements of an unpredictable nature.

Results

Seventy-one species including the cyclopoid and calanoid copepodids and nauplii representing 39 genera were identified during the period of collection from August 1996 through September 1997. Species belonging to 30 genera include the nauplii and copepodid stages for the copepods were used in this analysis. Nine genera were omitted due to their infrequent occurrence (present in less than ten percent of the samples). Tables 1 and 2 summarize the mean number of organisms per liter, components of variance and the spatial variance ratios for zooplankton abundance for the station and zone level of analyses, respectively. With the exception of five genera, station or zone and month factors and their interaction are highly statistically significant ($p<<0.01$). Only the genera for which the station, month, and interaction terms were statistically significant ($p<<0.01$) are included in Figures 2 and 3. The station component of variance describes the horizontal spatial variation associated with predictable patchiness of zooplankton for a station or zone independent of month. Large station component values are associated with hydrological or morphometric factors which influence the ability of a station or zone to produce and support zooplankton. Most of the genera exhibited large station component values as would be expected for reservoirs where permanent physical and chemical gradients are present due to their inherent nature. The interaction component

describes zooplankton patchiness through time most likely due to factors of an unpredictable nature such as turbulence and water movements. The interaction value for most genera was small. Temporal variation in zooplankton abundance through time is described by the month component and is large for most genera. Variance due to error was generally small (< 2%).

The relative importance of spatial and temporal variation in the top 10 meters differed between genera and groups. The relative position of each genus, when graphically displayed, is the same regardless of whether the analysis was performed at the station or zone level (Figures 2 and 3, respectively); therefore the results are the same. Of the two types of spatial variation, fixed horizontal spatial variation was more important than ephemeral variation for all genera except the rotifer genus *Ascomorpha*. *Ascomorpha* was present at all stations in November with the greatest abundance in the shallower upper stations and zones after which time its presence was patchy and then declined entirely after June 1996. In general, for all genera, temporal variation was more important than spatial variation. The spatial component of variance was greater than temporal for a single cladocera genus, *Diaphanosoma* , 4 of the 7 copepod genera, nauplii and the rotifer genera, *Ascomorpha*, *Notholca*, and *Synchatea* (Table 1 and 2). For the zone analysis, the rotifer genus, *Trichocera* was also included.

Tables 3 and 4 summarize the components of variance percentages and the spatial variance ratios for 21 physical and chemical parameters for the station

and zone levels of analysis respectively. Station or zone and month factors and their interaction were statistically significant ($p<<0.01$) for all parameters. Station and zone variance percentages describe the fixed horizontal spatial differences in the top 10 meters of the water column for these parameters independent of month. Large station component values are characteristic of hydrological, biological or morphometric factors, which influence the chemical and physical characteristics of a station or zone. The relative magnitude of station and interaction component values was generally larger in the zone analysis than the station analysis. The interaction component describes changes in water quality parameters through time most likely due to factors of an unpredictable nature such as hydrologic events and wind speed. Temporal variation in the physical and chemical parameters through time is described by the month component and is large for most parameters. Error was consistently small for both groups (< 1.7 %).

The relative importance of spatial and temporal variation differs between the physical chemical parameters and also between station and zone level of analyses (Figures 2 and 3, respectively). Of the two types of spatial variation, fixed horizontal spatial variation was more important than ephemeral variation for all parameters. At the station level, 7 parameters (chloride, sodium, total suspended solids, Secchi transparency, conductivity, turbidity, and total dissolved solids) were associated with fixed spatial variation compared to 12 parameters at the zone level. The 5 additional parameters at the zone level

included alkalinity, total phosphorus, potassium, total nitrogen and calcium. At the station level of analysis, temporal variation was greater than spatial variation for 14 of the 21 parameters. At the zone level of analysis, temporal variation was no greater than spatial variation because almost equal numbers of parameters were in each group.

Discussion

Spatial variation for Lake Texoma zooplankton and physical and chemical parameters was divided into a horizontal fixed component and an ephemeral component for stations and zones as described in Lewis (1978). The horizontal fixed component of spatial variation is associated with temporally stable differences in zooplankton abundance or water characteristics between stations and zones independent of time. Temporally stable differences in zooplankton abundance may result from fixed abundance gradients of various kinds or from fixed patches (Lewis, 1979). Temporally stable differences in water characteristics may result from longitudinal gradients formed due to the inherent nature of reservoirs or inflow from more local point sources or small tributaries. Ephemeral spatial variation is associated with space-time interactions. In the case of zooplankton, ephemeral spatial variation describes random horizontal patchiness that changes through time. For reservoir water characteristics, ephemeral spatial variation describes random changes through time associated with frequency of storms, drought, strength of winds, flow rate and dam regulation activities.

Temporal variation was more important than spatial variation for most zooplankton genera both at the zone and station levels of analysis. The implication is that, for Lake Texoma, seasonality was more influential in structuring the zooplankton community than the physical and chemical water quality. Seasonal dynamics in zooplankton abundance were typical of those observed for temperate reservoirs: a sharp spring increase followed by a summer decline and then a second, more modest increase in the fall (Taub and Wiseman 1998, Threlkeld 1983). Many of the species, especially those of the cladocera and rotifers, showed definite seasonal trends. Temporal variation was greater than spatial variation for about half the species of zooplankton in Lake Lanao (Lewis 1978); however, for Normandy Reservoir, spatial variation was generally greater than temporal variation. The bias towards spatial variation in Normandy Reservoir was attributed to the short time scale of the study - summer only (Threlkeld 1983). The spatial component of variance has a much greater relative importance in the large cladoceran *Diaphanosoma*, and the copepod genera, *Cyclops*, *Acanthocyclops*, and *Ectocyclops* than in other zooplankton genera.

The relative importance of temporal and spatial variation in the physical and chemical variables differed between station and zone analyses. Temporal variation was more important than spatial variation for two-thirds of the physical and chemical variables measured in Lake Texoma when analyzed by stations. However, when analyzed by zones, there appeared to be a balance between temporal and spatial variation in the physical and chemical variables. The

difference is a function of scale and supports the presence of physical and chemical gradients in Lake Texoma. Stations represent smaller areas of the lake than zones and therefore, weaker longitudinal gradients in some parameters are not as evident at the station level. For example, at the zone level, weak chemical gradients are present for alkalinity, total phosphorus, potassium, total nitrogen and calcium; however, at the station level they are associated with temporal effects. Regardless of analysis, temporal variability was primarily associated with parameters indicative of seasonal trends such as nutrients, dissolved oxygen, and temperature.

The spatial component of variance for the physical and chemical parameters was solely attributed to station or zone effects independent of time. Parameters associated with conductivity and turbidity (chloride, sodium, total suspended solids, Secchi transparency, conductivity, turbidity and total dissolved solids) exhibited a greater relative importance than the other parameters for both stations and zones. The fact that the relative magnitude of variance was greater in the zone analysis indicates the salinity and turbidity gradient is more pronounced for zones than stations. This outcome supports the presence of a strong chloride gradient and a weaker turbidity gradient in Lake Texoma. The absence of ephemeral variation in the physical and chemical parameters during this study further supports the presence of stable physical and chemical gradients in the top ten meters of Lake Texoma. These results concur with those of a similar study on Normandy Reservoir, in which physical and chemical

variation was solely attributed to fixed spatial variation indicating the presence of stable longitudinal gradients (Threlkeld 1983).

In conclusion, Lewis' hypothesis that systems with dominant fixed spatial gradients in their water quality characteristics should also have dominant fixed spatial components of variance in their zooplankton communities was upheld by results from this study. Water quality parameters associated with turbidity and conductivity exhibited dominant fixed spatial effects supporting the presence of stable gradients in water quality characteristics independent of time. This is evidenced by the pronounced chloride gradient and a weaker turbidity gradient present in Lake Texoma. Likewise, many of the copepods and a single cladocera genera (*Diaphanosoma*) also had dominant fixed spatial components of variance supporting the presence of temporally stable community gradients. In general the same patterns were observed at both the station and zone levels of analysis; however, the patterns were much stronger in the zone analysis which supports the existence of longitudinal gradients in water quality characteristics.

Table 1 Mean abundances (organisms per liter) for zooplankton genera, components of variance and spatial component ratios for 16 stations and 11 sampling trips from August 1996 through September 1997 for the station level of analysis. Unless otherwise indicated, for all genera, the station and month factors and their interaction are statistically significant ($p<<0.01$).

		Variance Component Percentages							
	Mean			Inter-			Spatial Variance Ratios		
Genera	(Org/L)	Station	Month	action	Error		Fixed		Ephemeral
Cladocera									
Bosmina	9.6	35.7	53.4	10.4	0.5		0.67		0.19
Ceriodaphnia	1.5	10.4	85.5	3.5	0.5		0.12		0.04
Daphnia	12.0	1.9	95.6	2.3	0.2		0.02		0.02
Diaphanosoma	3.0	61.8	14.5	20.6	3.1		4.26	*	1.42
Leptadora		9.2	78.2	7.3	5.3	ns	0.12		0.09
Calanoida									
Diaptomus	6.2	5.8	91.6	2.1	0.5		0.06		0.02
Eurytemora	1.5	45.5	34.3	18.1	2.0		1.33	*	0.53
Cal. copepodites	2.1	5.2	85.0	9.1	0.7		0.06		0.11
Cyclopoida									
Acanthocyclops	1.2	69.9	22.2	6.4	1.6		3.15	*	0.29
Cyclops	1.0	43.9	25.8	24.8	5.5		1.70	*	0.96
Ectocyclops	1.1	38.1	21.3	31.7	8.8		1.79	*	1.49
Ergasilus	0.6	23.7	49.9	18.9	7.5		0.47		0.38
Mesocyclops	1.7	11.6	81.1	6.3	0.9		0.14		0.08
Cyc. copepodites	9.4	17.0	77.9	4.7	0.4		0.22		0.06
nauplii	39.1	41.9	48.7	8.4	1.0		0.86	*	0.17
Rotifera									
Ascomorpha	17.4	25.3	39.9	33.8	1.0		0.63	*	0.85
Asplanchna	4.0	4.4	69.7	24.5	1.4		0.06		0.35
Brachnionus	32.5	22.3	76.3	1.3	0.1		0.29		0.02
Colletheca		37.2	37.5	14.4	10.9	ns	0.99		0.38
Conochilus	2.1	6.1	57.7	26.2	10.0		0.11		0.45
Filinia	1.1	37.0	50.5	10.3	2.2		0.73		0.20
Gastropus		11.9	82.8	3.1	2.2	ns	0.14		0.04
Hexarthra		45.1	37.6	9.1	8.3	ns	1.20		0.24
Keratella	27.7	14.6	81.7	3.5	0.2		0.18		0.04
Notholca	1.5	39.8	33.4	24.8	2.1		1.19	*	0.74
Platyias	9.9	28.1	58.4	12.7	0.9		0.48		0.22
Polyarthra	5.0	11.5	82.8	5.0	0.8		0.14		0.06
Pomphylox		2.5	56.9	28.6	12.0	ns	0.04		0.50
Synchaeta	6.3	38.3	41.4	19.3	1.0		0.93	*	0.47
Trichocera	0.5	25.3	68.6	4.4	1.7		0.37		0.06

* fixed spatial variation > ephemeral spatial variation

ns = not significant

Table 2 Mean abundances (organisms per liter) for zooplankton genera, components of variance and spatial component ratios for 5 zones and 11 sampling trips from August 1996 through September 1997 for the station level of analysis. Unless otherwise indicated, for all genera, the station and month factors and their interaction are statistically significant ($p<<0.01$).

		Variance Component Percentages					Spatial Variance Ratios		
Genera	Mean (Org/L)	Zone	Month	Inter-action	Error		Fixed		Ephemeral
Cladocera									
Bosmina	9.6	35.67	53.42	10.37	0.54		0.67		0.19
Ceriodaphnia	1.5	23.73	68.35	7.37	0.55		0.35		0.11
Daphnia	12.0	1.96	92.43	5.32	0.29		0.02		0.06
Diaphanosoma	3.0	61.76	14.50	20.59	3.14		4.26	*	1.42
Leptadora		9.2	78.2	7.3	5.3	ns	0.12		0.09
Calanoida									
Diaptomus	6.2	14.46	81.82	3.14	0.57		0.18		0.04
Eurytemora	1.5	45.54	34.35	18.09	2.02		1.33	*	0.53
Cal. copepodites	2.1	5.21	84.99	9.09	0.71		0.06		0.11
Cyclopoida									
Acanthocyclops	1.2	69.86	22.17	6.41	1.56		3.15	*	0.29
Cyclops	1.0	61.24	14.95	19.03	4.78		4.10	*	1.27
Ectocyclops	1.1	38.14	21.27	31.75	8.84		1.79	*	1.49
Ergasilus	0.6	23.69	49.92	18.85	7.53		0.47		0.38
Mesocyclops	1.7	21.87	65.18	11.93	1.02		0.34		0.18
Cyc. copepodites	9.4	29.88	64.04	5.24	0.84		0.47		0.08
nauplii	39.1	41.93	48.70	8.39	0.98		0.86		0.17
Rotifera									
Ascomorpha	17.4	25.27	39.90	33.81	1.01		0.63	*	0.85
Asplanchna	4.0	4.37	69.74	24.47	1.42		0.06		0.35
Brachnionus	32.5	48.01	49.98	1.84	0.17		0.96		0.04
Colletheca		37.2	37.50	14.37	10.89	ns	0.99		0.38
Conochilus	2.1	6.14	57.70	26.20	9.96	ns	0.11		0.45
Filinia	1.1	36.96	50.52	10.34	2.17		0.73		0.20
Gastropus		11.93	82.76	3.10	2.22	ns	0.14		0.04
Hexarthra		45.06	37.57	9.09	8.27	ns	1.20		0.24
Keratella	27.7	34.57	59.31	5.80	0.32		0.58		0.10
Notholca	1.5	39.80	33.39	24.76	2.05		1.19	*	0.74
Platyias	9.9	28.06	58.35	12.72	0.87		0.48		0.22
Polyarthra	5.0	27.17	63.09	8.97	0.78		0.43		0.14
Pomphylox		2.51	56.88	28.60	12.02	ns	0.04		0.50
Synchaeta	6.3	38.29	41.38	19.32	1.01		0.93	*	0.47
Trichocera	0.5	52.57	40.68	5.66	1.08		1.29	*	0.14

* fixed spatial variation > ephemeral spatial variation
ns = not significant

Table 3 Mean physical chemical parameter values, components of variance and spatial component ratios for 16 stations and 11 sampling trips from August 1996 through September 1997 for the station level of analysis. Units are mg/L unless otherwise stated.

			Variance Component Percentages				Spatial Variance Ratios		
Parameter	Code	Mean	Station	Month	Inter-action	Error	Fixed		Ephemeral
Conductiivity (uS/cm)	1	1680	67.29	30.20	2.46	0.05	2.23	*	0.08
Dissolved Oxygen	2	7.64	1.59	96.56	1.45	0.40	0.02		0.01
pH (standard units)	3	8.08	16.15	81.06	1.07	1.73	0.20		0.01
Secchi transparency (m)	4	0.9	68.85	28.44	2.67	0.03	2.42	*	0.09
Temperature (^{o}C)	5	20.51	0.11	99.75	0.13	0.01	0.00		0.00
Akalinity	6	129	37.61	60.20	2.17	0.03	0.62		0.04
Calcium	7	118	22.89	69.98	6.95	0.18	0.33		0.10
Chloride	8	281	71.50	26.70	1.79	0.01	2.68	*	0.07
Chlorophyll-*a* (ug/L)	9	17.88	10.45	86.45	3.04	0.06	0.12		0.04
Magnesium	10	38.99	5.72	87.91	6.26	0.12	0.07		0.07
Nitrate	11	0.23	8.67	90.20	1.07	0.06	0.10		0.01
Nitrite	12	0.00	13.84	78.52	7.25	0.39	0.18		0.09
Total Nitrogen	13	0.59	26.39	67.57	5.36	0.68	0.39		0.08
Orthophosphate	14	0.01	13.85	82.15	3.66	0.33	0.17		0.04
Total Phosphorus	15	0.05	39.17	55.91	4.02	0.91	0.70		0.07
Potassium	16	6.13	29.81	69.58	0.59	0.01	0.43		0.01
Sodium	17	184	71.04	27.31	1.64	0.02	2.60	*	0.06
Sulfate	18	334	10.44	86.60	2.96	0.01	0.12		0.03
Turbidity (NTU)	19	9.55	58.50	39.99	1.49	0.01	1.46	*	0.04
Total Dissolved Solids	20	1095	54.94	42.12	2.93	0.01	1.30	*	0.07
Total Suspended Solids	21	9.72	69.47	27.31	3.13	0.09	2.54	*	0.11

* fixed spation variation > ephemeral spatial variation

Table 4 Mean physical chemical parameter values, components of variance and spatial component ratios for ratios for 16 stations and 11 sampling trips from August 1996 through September 1997 for the zone level of analysis. Units are mg/L unless otherwise stated.

			Variance Component Percentages				Spatial Variance Ratios		
Parameter	Code	Mean	Zone	Month	Inter-action	Error	Fixed		Ephemeral
Conductiivity (uS/cm)	1	1680	86.68	10.87	2.37	0.08	7.98	*	0.22
Dissolved Oxygen	2	7.64	3.60	92.70	3.27	0.43	0.04		0.04
pH (standard units)	3	8.08	32.81	50.10	15.71	1.37	0.65		0.31
Secchi transparency (m)	4	0.9	86.56	11.25	1.87	0.32	7.70	*	0.17
Temperature (^{o}C)	5	20.51	0.27	99.43	0.28	0.02	0.00		0.00
Alkalinity	6	129	66.53	30.76	2.51	0.20	2.16	*	0.08
Calcium	7	118	46.72	41.66	11.14	0.48	1.12	*	0.27
Chloride	8	281	89.03	9.19	1.70	0.08	9.69	*	0.19
Chlorophyll-*a* (ug/L)	9	17.88	24.13	69.50	6.16	0.21	0.35		0.09
Magnesium	10	38.99	9.68	75.56	14.10	0.66	0.13		0.19
Nitrate	11	0.23	23.18	74.37	2.29	0.15	0.31		0.03
Nitrite	12	0.00	25.35	59.74	14.01	0.90	0.42		0.23
Total Nitrogen	13	0.59	50.78	42.37	5.86	0.99	1.20	*	0.14
Orthophosphate	14	0.01	33.00	60.33	6.11	0.56	0.55		0.10
Total Phosphorus	15	0.05	64.13	31.20	3.75	0.92	2.06	*	0.12
Potassium	16	6.13	60.32	38.88	0.73	0.06	1.55	*	0.02
Sodium	17	184	89.00	9.44	1.48	0.08	9.43	*	0.16
Sulfate	18	334	26.41	66.77	6.62	0.19	0.40		0.10
Turbidity (NTU)	19	10	81.38	17.04	1.48	0.10	4.77	*	0.09
Total Dissolved Solids	20	1095	79.49	17.15	3.21	0.15	4.63	*	0.19
Total Suspended Solids	21	9.72	86.13	11.13	2.33	0.41	7.74	*	0.21

* fixed spatial variation > ephemeral variation

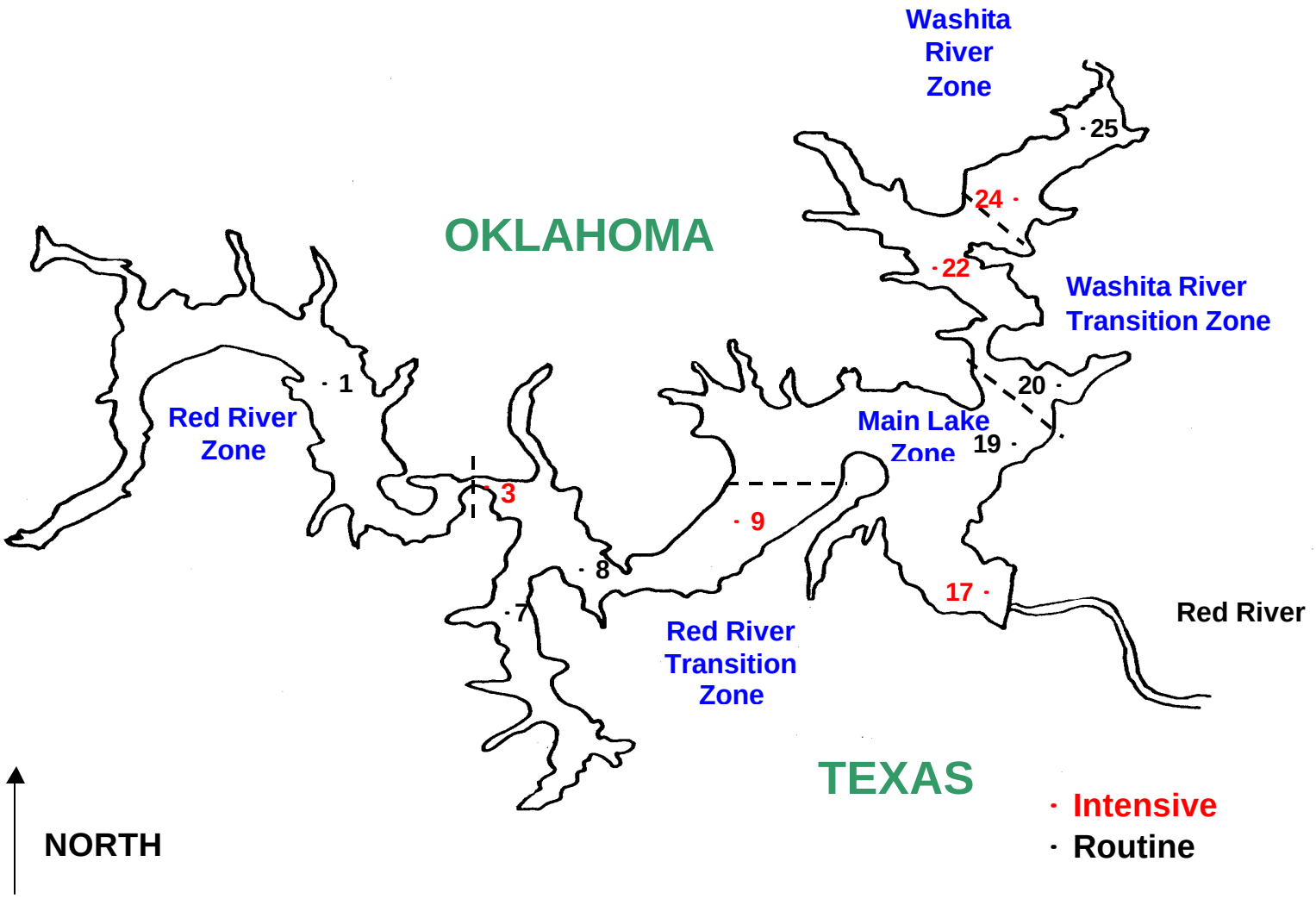

Figure 1 Map of Lake Texoma showing routine and intensive fixed station locations with each zone.

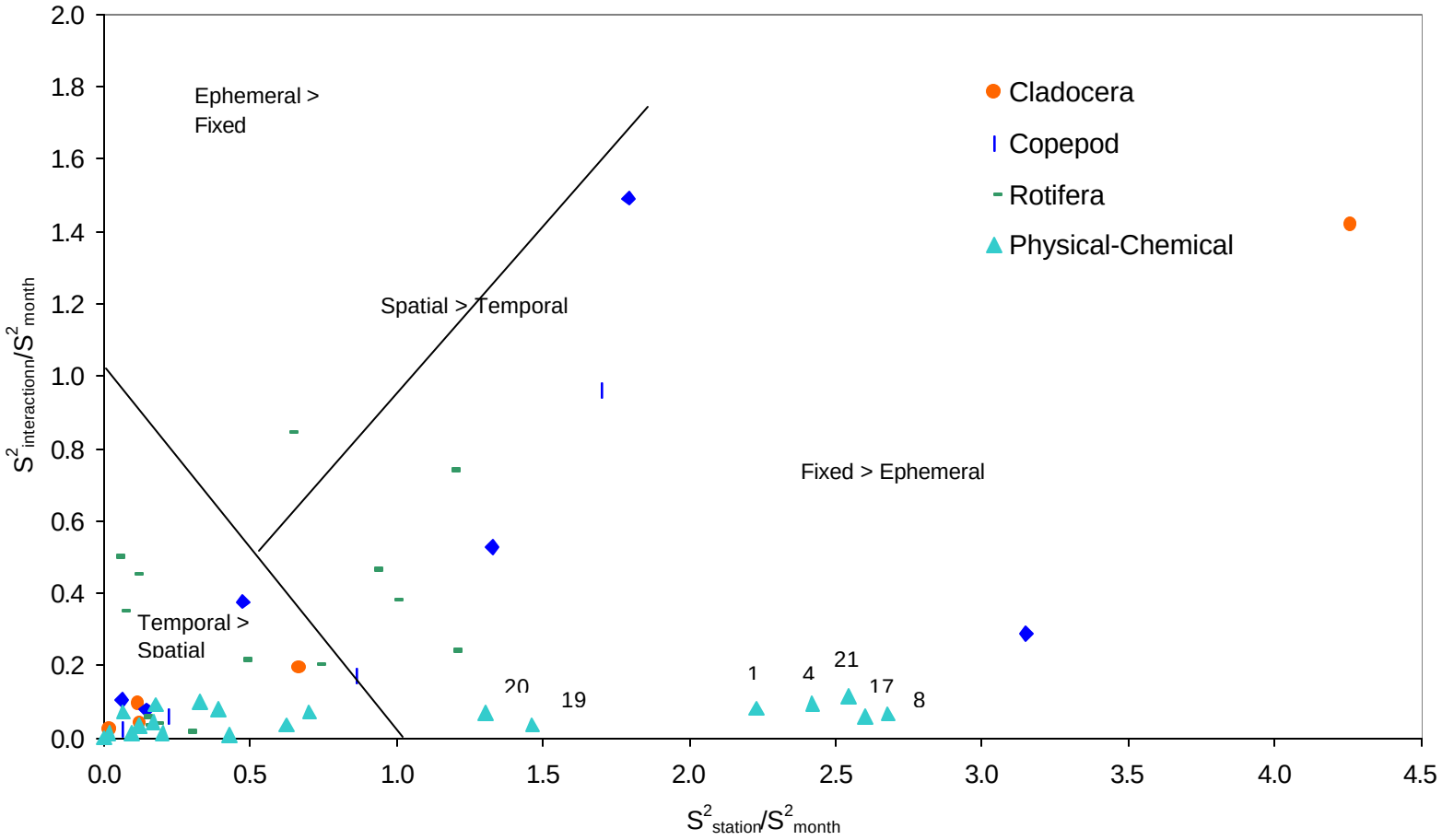

Figure 2 Ratios of variance components mapped against each other to show the relative importance of spatial variation (fixed or ephemeral) and temporal variation in zooplankton densities and physical and chemical measures for lake stations .

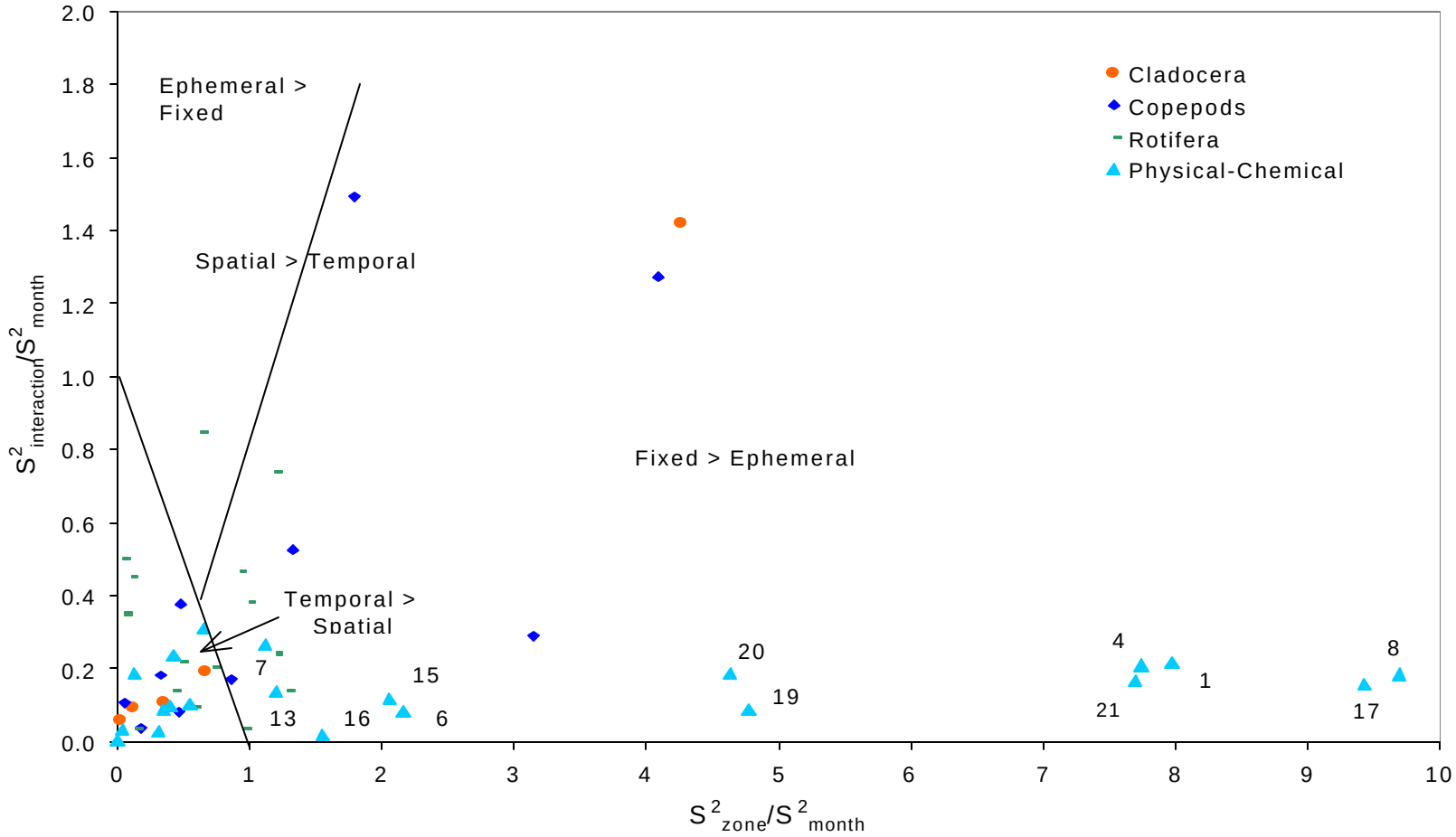

Figure 3 Ratios of variance components mapped against each other to show the relative importance of spatial variation (fixed or ephemeral) and temporal variation in zooplankton abundance and physical and chemical measures for lake zones.

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PATTERNS IN ZOOPLANKTON SPECIES COMPOSITION IN LAKE TEXOMA IN RELATION TO LAKE ZONATION, SEASON AND THE PHYSICAL AND CHEMICAL WATER QUALITY

Introduction

Patterns in zooplankton community structure are most often studied either at the regional scale or local scale. Regional-scale studies focus on patterns in community structure among many lakes or reservoirs over large regions (Tessier and Horwitz 1990, Stemberger and Lazorchak 1994). Often times, sampling is limited to a single near-dam station during the summer. In contrast, local-scale studies focus on the lake as a whole from which multiple samples have been collected from different locations in the reservoir over a much longer time period but generally a year or less. Multiple year studies are less frequent (Hart 1990, Beavers and Havens 1996). Occasionally, different regions or zones within a reservoir are analyzed independently. Beaver and Havens (1996) studied the zooplankton community associated with four ecological zones in Lake Okeechobee defined in a previous study by Philips and others (1995). Ecological zones were defined based on 10 limnological parameters integrating physical, chemical and biological characteristics of the lake. Hart (1990) examined zooplankton patterns in reservoir zones in relative to turbidity and related environmental gradients in Lake le Roux, South Africa.

Both biotic and abiotic factors are important in the structuring of zooplankton communities within a reservoir. Abiotic factors include the physical

and chemical properties of the water, seasonal factors, physical processes such as flow, currents, and stratification, and reservoir measurements describing lake morphometry, size and location. These types of factors have been shown to play a much larger role in community structure on a regional scale than biotic factors (Pinel-Alloul and other 1990, Pinel-Alloul and others 1995). In contrast, it is believed that food availability and predation (biotic factors) are more important in shaping zooplankton communities in single reservoirs.

Factors reported to affect community structure in single reservoir are numerous. Stratification provides refuge from predation and influences the size distribution of plankton (Tessier and Horwitz 1990). Fluctuating lake levels in Lake Okeechobee resulting from severe drought conditions in 1989 and 1990 positively affected zooplankton populations. As lake levels decreased, portions of the lake strongly influenced by nutrients (transition zone) expanded increasing zooplankton densities, especially rotifers (Beaver and Havens 1996). Composition of crustacean zooplankton populations decreased along a longitudinal turbidity gradient in Lake le Roux, South Africa (Hart 1990). The plankton community in two lakes in the Saimma lake system in Finland were shaped by a trophic gradient, predation between the algae and zooplankton, and regeneration and reorganization of nutrients. (Karjalainen and others 1996).

Lake Texoma impounds two rivers with differing water chemistry and flow regimes, therefore, different physical and chemical factors may play a role in shaping zooplankton community structure within the arms of reservoir. A major difference in the water chemistry throughout the reservoir is the presence of a

chloride gradient and a weaker gradient associated with water transparency and suspended solids. The flow in the Red River is greater and more variable than the Washita River (Gibbs 1998). The purpose of this research is to identify environmental variables that are important in the structuring of zooplankton communities in Lake Texoma for the whole lake, each river arm and the main lake body.

Methods

Lake Texoma is a 36,000 hectare multipurpose impoundment with a drainage basin of approximately 103,000 km^2, most of which is pasture and cropland. It occupies portions of both south central Oklahoma and north central Texas. Major rivers flowing into Lake Texoma are the Red River from the west, which forms the southern border between Oklahoma and Texas and the Washita River from the north. At normal pool elevation (617.0 ft), maximum depth is 34 m (112 ft) and mean depth is approximately 9 m (30 ft) (Atkinson and others 1999).

An *a priori* decision was made to divide Lake Texoma into 5 zones based upon the presence of a chloride gradient (Atkinson and others 1996). The 5 zones were the Red River zone, Red River Transition zone, Main Lake body, Washita River Transition Zone and Washita River zone. Three stations represent each zone: two fixed stations in the main channel and one random station. Random station locations were chosen randomly each month from a grid of all possible station locations within a zone with the stipulation that the depth was at least six meters. The purpose of the random station was to further

characterize the spatial distribution of zooplankton and water quality in each zone.

Triplicate zooplankton samples were collected from 10 stations and 10 replicate samples from 5 stations on 9 dates from March 1997 through September 1997 (Figure 1). Only the first three of the ten replicate zooplankton samples collected from the intensive stations were used in this analysis. Vertical tows were taken from ten meters to the surface using a No. 20 nylon plankton net fitted with a Wisconsin bucket (80 micron mesh). For stations less than 11 meters in depth, vertical tows were taken from one meter above the bottom to the surface. Station depth was determined using a Hummingbird™ wide view fish finder. Following collection, the Wisconsin bucket contents were thoroughly washed with distilled water into a prelabeled 125 ml polyethylene sample bottle and preserved with acifidied Lugols (Wetzel and Likens 1979). Individual zooplankton sample volumes were adjusted prior to enumeration so that at least 170 to 200 organisms would be counted from a 1 ml aliquot (EPA 1998). A compound microscope (125X) was used to count zooplankton from a 1 ml aliquot (obtained using a Hensen-Stemple pipette) placed in a Sedwick-rafter counting chamber. Zooplankton were identified to the lowest possible taxon following Edmondson (1959), Stemberger (1979) and Pennak (1989). Counts were converted to organisms per liter of lake water.

Temperature (^{o}C), dissolved oxygen (mg/L), conductivity (µS/cm) and pH (standard units) were measured with a Hydrolab H20 datasonde at two meter intervals beginning one meter below the surface and ending one meter above the

bottom at each station. Data collected from the first 9 meters of the water column were used in this analysis because this is the portion of the water column where zooplankton were collected. Triplicate secchi depth measurements were taken following the procedures described in (Lind 1985).

Triplicate whole water samples were collected from one meter below the surface for 16 water chemistry analyses. Although 10 replicate samples were collected for chlorophyll-a and turbidity analyses, only the first 3 were used in this analysis. Individual chemical parameters are listed in Appendix I. TRAC Laboratories, Denton, Texas completed the analyses except for chlorophyll-a which was analyzed at the University of North Texas. Analytical methods employed are based on EPA guidelines and standards adapted from APHA 1986.

Statistical Analyses

Two data sets were used in these analyses: 1) an environmental data set composed of physical and chemical data consisting of 16 variables measured by lab analyses and 4 variables measured in the field with a Hydrolab HP20 datasounde (Appendix I) and 2) a covariable data set consisting of 5 zones (Red River zone, Red River Transition zone, Main Lake zone, Washita River Transition zone and Washita River zone) and two seasons (spring and summer) coded as dummy variables (1 if present, 0 if not present). Prior to analyses, chemical and field variables (except pH) were log transformed (x +1) (Palmer 1993) and zooplankton species data were square-root transformed to down-weight high

abundances (ter Braak 1986). Species with low frequencies were eliminated from the data prior to analysis. Those species omitted from an analysis (shown with an "*" or "**" in Appendix II) are not necessarily unimportant, but often were littoral species that may have drifted on the currents into the limnetic regions of the lake.

A preliminary detrended correspondence analysis (DCA) was run using the program CANOCO 4.0 (ter Braak and Smilauer 1998) to determine the appropriate model for this data. As shown in Table 1, the resulting short gradient lengths (<3SD) indicate a linear model is appropriate (Verdonschot and ter Braak 1994) . Short gradient lengths indicate the zooplankton species are responding linearly to gradients as opposed to responding around an environmental optima (unimodal response). The data were then ordinated by redundancy analysis (RDA) using the program CANOCO 4.0. RDA is a multivariate linear direct gradient technique that is designed so that the ordination of matrix Y is constrained to be linear combinations of the variables in matrix X.

Prior to species analyses, patterns in the physical-chemical data set were also examined in relation to the 5 lake zones using a standardized principal components analysis (PCA) to establish a basis for separate analyses for the two river arms and main lake body rather than a single whole lake analysis. A standardized PCA was chosen because the physical-chemical data are measured in different units (Jongman and others 1995).

A global approach was taken initially to determine the contribution of the physical-chemical, season, and zone variables to patterns in whole lake

zooplankton community structure. For this analysis, all environmental variables (physical-chemical, season, and zone) were included in the model; however, because many of these were highly correlated, a RDA using forward selection was performed to reduce the number of variables to only those that contribute significantly to explaining total variance of the species data . Variables retained by the forward selection procedure having a high (>20) variance inflation factor (VIF) were removed singly beginning with the largest values until all the VIF's were < 20. A VIF greater than 20 means that the variable is almost perfectly correlated with the other variables and therefore does not uniquely contribute to the model (ter Braak and Smilauer 1998). The significance of each variable remaining in the model, as well as the first canonical axis, was tested ($P<0.05$) using a Monte Carlo permutation test (199 permutations). Subsequently, separate RDA's were performed on data representing the whole lake ignoring zones, Main Lake body, Red River arm and Washita River arm. Partial RDA ordination was used to describe the amount of variance explained independently by the physical-chemical, season, and zone variables in the RDA by specifying them as covariables in CANOCO. This results in an ordination of the residual variation in the species data after the covariables are factored out by multivariate linear regression. The outcomes from the RDA and Partial RDA were then used to partition the variance in species composition into independent components following Borcard and others (1992): The components consist of the following: a) pure physical-chemical variation (fraction of variance accounted for by the physical-chemical variables after removal of the variation in seasonal effects), b)

shared variation (fraction of the variance that is shared between the physical-chemical variables and seasonal variables), c) pure seasonal variation (fraction of variance accounted for by the season variables after removal of the variation accounted for by the physical-chemical variables), and d) unexplained variation (fraction of species variation that remains unexplained by the physical-chemical variables and seasonal variables.

Results

Zooplankton

Sixty-four distinct zooplankton taxa plus the calanoid and cyclopoid copepodids and nauplii were identified from 405 samples collected during the spring and summer from March 1997 through September 1997 (Appendix II). Differences in zooplankton community structure were found between the 3 lake zones with the Red River arm and Washita River arm exhibiting the greatest number of taxa (69 and 64, respectively) and the Main Lake body the least number of taxa (50). Differences in taxa between lake areas occurred only in the cladoceran and rotifer taxa. Comparing the two arms, the Red River arm had fewer rotifer taxa, whereas the Washita River arm had fewer cladoceran taxa. Comparing the Main Lake body to the two arms, the Main Lake had considerably fewer cladoceran and rotifer taxa. There was no difference in the number of copepod taxa between lake zones.

Differences in zooplankton abundance and percent composition were also found between the 3 lake zones (Figure 2). Greatest abundances occurred in

the Red River arm (mean 151.4 org/L, SD 103.0), intermediate abundances in the Main Lake (mean 121.7 org/L, SD 72.1) and lowest abundances in the Washita River arm (mean 107.2 org/L, SD 57.5). Copepods (including the nauplii) accounted for the greatest proportion of the zooplankton community, followed closely by the rotifers with the cladocera making up a significantly smaller proportion. This same pattern was observed for each zone, but differences in the percent contribution of each group was noted between zones. The percent composition was most similar in the Red River arm and Main Lake body in that the copepods accounted for 50% to 60% of the composition. The remaining 40% to 50% were almost equally shared between the rotifers and cladocera. In contrast, in the Washita River arm, greater than 90% of the zooplankton were accounted for equally by the copepods and rotifers leaving less than 10% for the cladocera. Similar percentages of cyclopoids and calanoids were found in the Red River arm and Washita River arm with greater percentages found in the Main Lake body. The greatest differences were found among the cyclopoids rather than the calanoids.

Chemical gradients

Historical (Atkinson and others 1996) and current data (Appendix I) support the presence of a strong stable chloride gradient. Two rivers with differing water chemistry flow into Lake Texoma. The Red River originates in the Panhandle of Texas and flows through soils rich in calcium carbonate, calcium sulfate and marine evaporite salt (sodium chloride) deposits formed by the subsidence of inland Permian seas (Sonnenfield 1984). Resulting chloride

concentrations are much higher in the Red River arm of the reservoir (range: 258 to 562 mg/L) compared to the Washita River arm (range: 24 to 295 mg/L). Intermediate concentrations are found in the main lake body (range 147 to 316 mg/L) where waters from the two rivers mix. Other water chemistry parameters that tend to mirror that of chloride are calcium, potassium, sodium and sulfate of which calcium, potassium and sodium readily form compounds with chloride and sulfate. Total dissolved solids, as expected, follow the same trend.

A transparency gradient is also present (Appendix I). Secchi disk transparency, on average, doubles from the headwaters of the Red River and Washita River (0.75 m and 0.74 m, respectively) to the main lake body (1.53 m). Total suspended solids (TSS) are much greater on average in the two arms (15.49 mg/L and 10.34 mg/L, Red River arm and Washita River arm respectively) than the main lake body (1.72 mg/L). However, the mean value is about a third greater in the Washita River arm than the Red River arm indicating the Washita River arm has a higher sediment load.

Four models were developed to describe patterns in zooplankton community structure in Lake Texoma: 1) whole lake model, 2) Red River arm model, 3) Main Lake model, and 4) Washita River arm model. The decision to model the arms of Lake Texoma separately from the Main Lake body was based upon the results of a standardized PCA using the mean value per zone for 9 sampling periods for the physical-chemical variables (20 variables). The resulting correlation biplot of physical-chemical parameters and zones on the first two axes (Figure 3) show 3 clusters: the Red River arm in the left upper corner

(Red River zone and Red River Transition zone), the Washita River arm in the upper and lower right corners (Washita River zone and Washita River Transition zone), and the Main Lake zone in the lower left corner. The diagram explains 63% of the total variance in physical-chemical values. Chloride, conductivity, total dissolved solids, potassium, sulfate, and calcium are strongly positively correlated to the Red River arm and alkalinity and nitrite are positively correlated to the Washita River arm. Secchi disk depth is positively correlated to the Main Lake body. Based upon these results, the zooplankton data were grouped into 3 zones (the saline Red River arm, the alkaline Washita River arm, and more transparent Main Lake body) for independent analysis. Prior to analysis, 21 taxa (those with an "*" in Appendix II) were omitted because of their infrequent occurrence. The whole lake zooplankton data matrix consists of 69 taxa including the nauplii and copepod copepodids. The data matrix for the Main Lake model consists of 50 taxa and 69 taxa and 64 taxa, respectively, for the Red River arm and Washita River arm models. Differences in the number of taxa used for each independent analysis occurred because not all species were found in every zone and some zones had lower frequencies of some taxa than others.

Global Approach

The results of the global approach shows that all 3 types of environmental factors (season, zone, and physical-chemical) significantly influence the zooplankton community structure in Lake Texoma ($P \leq 0.005$, Table 2). After forward selection and subsequent removal of factors with VIF values > 20, one

seasonal, 4 zonal, and 15 physical-chemical variables are retained in the global model. Table 3 shows the relative importance of each environmental factor in the global model. The pure contribution of the 15 physical-chemical variables (16.5%) is significant (P=0.005) and larger than both the purely seasonal contribution (3.6%) and purely zonal contribution (3.2%) combined, both of which are also significant (P=0.005). The fact that all environmental factors are significant indicates that all contribute to the 28.6% shared variance component. The high unexplained variation (58.1%) indicates that other factors not included in this study have an influence on zooplankton community structure in Lake Texoma.

Separate Analyses

Figure 4 compares the relative importance of the pure physical-chemical fraction, the pure seasonal fraction, the seasonally structured physical-chemical fraction and the unexplained fraction for each of the 4 models: whole lake model, Main Lake model, Red River arm model and Washita River arm model. For all models, the pure contribution of the physical-chemical fraction is significant (P = 0.005) and ranges from 42.3% in the Main Lake model to 21.6% in the whole lake model. Likewise, for all models, this fraction is much larger than the purely seasonal significant (P = 0.005) fraction, which ranges from 5.5% in the Washita River arm to 1.9% in the Main Lake. Since both the physical-chemical and seasonal fractions are significant, they both contribute to the shared variance component that ranges from 27.7% in the Washita River arm model to 23.5% in the whole lake model. The unexplained variation ranges from 50.85% in the

whole lake model to 30.4% in the Main Lake model. Unexplained variation in the model is due to factors (abiotic or biotic) not accounted for in the study, which influence zooplankton community structure.

The number of statistically significant ($P \leq 0.05$) variables retained in each model is similar; 16 in the whole lake model, 15 in the Red River arm model, and 14 in the Main Lake and Washita River arm models. All models retained a single seasonal factor, spring or summer. Although there was at most a difference of 2 physical-chemical variables retained among the 4 models, each model was influenced by a different combination of physical-chemical variables (Table 4). This is not surprising due to the strong chloride, calcium, and conductivity gradient present in Lake Texoma (Appendix I). Chloride was retained only in the Red River arm model because of its significant influence in the water chemistry makeup of that zone. Likewise, dissolved oxygen and total phosphorus was retained only in the Main Lake model.

The RDA results for each model is displayed in the form of a species-environment ordination biplot in which the quantitative physical and chemical variables are represented by solid arrows, the qualitative seasonal variables by dashed arrows, and taxa by points (Figures 5-8). Only the environmental variables retained in each model after forward selection and removal of variables with high VIF values are shown. The strength of an environmental gradient can be implied from the length of its arrow; therefore, the longer the arrow, the greater its strength. Likewise, the relationship between taxa (points) and environmental gradients (arrows) can be inferred from their position in relation to

the gradient. Taxa whose points are in close proximity to an environmental gradient are highly correlated with that gradient (Jongman and others 1995). To reduce clutter in the biplot, only taxa for which 30% of the variance is accounted for by the diagram are displayed (ter Braak 1994). For the whole lake model (Figure 5), canonical axis I (32.7%) and axis II (4.9%) explain a significant amount of the variance in the species-environment biplot. Season (r = 0.91), temperature (r= 0.67), chlorophyll-a (r = 0.60) and nitrate (r = -0.69) are highly correlated with axis I. Calcium (r = 0.78), and sulfate (r = 0.67) are highly correlated with axis II. A considerable portion of the taxa distribution is associated with either the summer or spring gradient. The rotifer species, *Brachionius*, is more correlated with axis II which is represented by variables associated with salinity. For the Main Lake model (Figure 6), RDA axes I and II explain 35.1% and 10.7%, respectively, of the variance in ordination diagram. Season (r = 0.83), nitrate (r= 0.0.73), alkalinity (r = 0.64) and dissolved oxygen (r = 0.61) are highly correlated with axis I. Total suspended solids (r = 0.56), chlorophyll-a (r = 0.56) and calcium (r = 0.55) are moderately correlated with axis II. The cladoceran, *Daphnia galaeta mendotae*, the cyclopoid copepodids, the calanoid species, *Diaptomus,* and the copepod nauplii are all associated with the alkalinity gradient. Although a strong seasonal gradient is present, its influence on zooplankton patterns is weak. For the Red River model (Figure 7), RDA axes I and II explain 38.6% and 7.1%, respectively, of the variance in the species-environment biplot. Season (r = 0.88), and temperature (r= 0.61) are highly correlated with axis I. Calcium (r = 0.66), potassium (r = 0.63) chloride (r = 0.61)

and sulfate (r = 0.61) are highly correlated with axis II. The strong seasonal gradient has a major influence on the zooplankton community. For the Washita River arm model (Figure 8), canonical axis I and II explain 39.7% and 6.5%, respectively, of the variance in the ordination diagram. Season (r = 0.91), nitrate (r = -0.75), temperature (r = 0.71), and chlorophyll-a (r = 0.71) are highly correlated with axis I. Calcium (r = -0.61), and sodium (r = -0.55) are moderately inversely correlated with axis II. Species distributions appear to be highly related to the spring seasonal gradient.

Discussion

Lake Texoma is a large and dynamic reservoir with inflows from two rivers of differing water quality. Examination of physical and chemical factors in relation to 5 reservoir zones (defined *a priori*) using redundancy analysis separated the reservoir into 3 regions or zones: 1) Red River arm, 2) the Main Lake body, and 3) the Washita River arm (Figure 2). Models describing the relationship between the zooplankton community and environmental variables were developed for each of these zones and the whole lake. Unexplained variance in the whole lake model was reduced by 20% in the Red River arm and Washita River arm models and by 40% in the Main Lake model (Figure 3). Therefore, 3 separate models, rather than a single model for the entire reservoir, best describe patterns in the zooplankton community and its relationship to seasonal and physical and chemical factors.

For all models, the physical and chemical factors alone explained on average 90% more of the variation in the zooplankton community than the seasonal factors alone (Figure 4). Shared variance between the two sources was almost as great as that explained by the physical and chemical factors alone. Although, the amount of pure seasonal variation was small, this factor contributed the greatest amount of explained variation of any single factor (Table 2 and 4) in all models. Different combinations of a few variables within each zone explain a large amount of the physical and chemical variance in each model (Table 4). For example, temperature, chlorophyll-a, and alkalinity had the greatest effect on the Red River arm model. Nitrate, temperature, and chlorophyll-a significantly influenced the Washita River arm model and nitrate, potassium and alkalinity contributed the most to the Main Lake model. The amount of unexplained variation in the models ranges from 30% to 39%. Unexplained variation is due in part to unmeasured external factors in community dynamics including, but not limited to the influence of phytoplankton and fish on zooplankton composition variation (Pace and Orcutt, Jr. 1981, Rodriguez and others 1993, Pinel-Alloul 1995, Pinel-Alloul and others 1995).

Differences were observed in the densities (Figure 2) and percent composition of zooplankton among the different zones. There was a decreasing density among zones, with the Red River arm exhibiting the greatest densities and the Washita River arm the least. This same pattern was reported by Crist (1980) for a one-year study. Percent composition of zooplankton abundance in Lake Texoma was typical of that for temperate reservoirs. Copepods (including

the nauplii) accounted for the greatest proportion of the zooplankton community, followed closely by the rotifers with the cladocera making up a significantly smaller proportion. This same pattern was observed for each zone, but differences in the percent contribution of each group was noted between zones. The percent composition was most similar in the Red River arm and Main Lake body in that the copepods accounted for 50% to 60% of the composition with the remaining 40% to 50% being almost equally shared between the rotifers and cladocera. In contrast, in the Washita River arm, greater than 90% of the zooplankton were accounted for equally by the copepods and rotifers leaving less than 10% for the cladocera.

Differences in zooplankton community structure between the different zones occurred only in the cladocera and rotifer groups (Appendix II). The two river arms had similar numbers of taxa; however, the Washita River arm had 4 less cladocera species and one less rotifer species. Thirty percent fewer species were found in the Main Lake body consisting of 6 cladocera species and 13 rotifer species. This is typical of a river-run system in which fewer taxa are found in the nutrient poor, deeper, less turbid near-dam region. The two arms behaved similarly with respect to community structure suggesting that factors other than physical and chemical ones are more influential in structuring the zooplankton community.

Few zooplankton taxa were highly associated with the summer season. The summer zooplankton community for all zones can be characterized by a single copepod species (*Ergasilus versicolor*), two cladocera species (*Daphnia*

lumholtzi and *Diaphanosoma* bergei), and three rotifer taxa (*Platyias patulus, Asplanchna spp,* and *Trichocera spp*.). Two additional species characterize the Main Lake body, the copepod, *Ectocyclops phaleratus* and rotifer, *Brachionus angularis*. Several rotifer species of the genus, *Brachnious*, were associated with summer in the Red River arm.

The Red River arm zone is characterized by its significantly higher chloride concentrations and greater flow. It is often red in appearance, especially after heavy rains, due to suspended sediments in the water column. The zooplankton community is the most diverse, comprised of 69 taxa (Appendix II), and the most abundant (Figure 2). Copepods make up 50% of the zooplankton abundance with the remaining 50% shared almost equally between the rotifers and cladocera. Typically, the rotifers will account for a much greater percent of the zooplankton community, which is not the case. Although the chloride gradient is strong, it has little influence on the distribution of zooplankton (Figure 7). Of the chemical variables, alkalinity has the greatest influence on the crustacean zooplankton community. Seasonal variation appears to be the driving force in the zooplankton community, rather than the physical and chemical makeup of the water in this zone.

In contrast to the Red River arm, the Washita River arm zone is often more turbid possibly due to its reduced flow. It is often brown in appearance because of the sediments in the water. The zooplankton community is similar to that of the Red River, but has one less cladocera species and three less rotifer species. Species abundances are lowest for this zone. The composition of the

zooplankton community is dominated almost equally by copepods and rotifers with a very low percentage of cladocera. The cladocera, *Daphnia lumholtzi* and *Diaphanosoma bergei* and the rotifer, *Polyarthra dolichoptera* are highly correlated with chlorophyll-a. The abundance of the calanoid copepod, *Diaptomus connexus* and the copepodids, together with young *Daphnia* are highly correlated with nitrate. Several of the cyclopoid copepods and the cladocera, *Leptodora kindit*ii, are highly correlated with nitrite. As in the Red River arm, seasonal variation appears to be the driving force in the zooplankton community, rather than the physical and chemical makeup of the water in this zone.

The Main Lake zone is the most stable of the zones being less influenced by the dynamic hydrologic regimes in the river arms. Flow is much reduced and much of the suspended solids have settled out accounting for the increased clarity in the water column. Considerably fewer zooplankton species are present and abundances are intermediate between that of the Red River arm and Washita River arm. The copepods account for the majority of the zooplankton composition, as in the other zones. The cladocera makeup the second greatest percentage; which is much greater than that in the Washita River arm and smaller than that in the Red River arm. As expected, the rotifers make up the smallest percentage. *Ceriodaphnia spp*., young daphnids and the calanoid, *Eurytemora affinis* are highly correlated with dissolved oxygen and nitrate. The cyclopoid copepodids, calanoid, *Diaptomus connexus*, nauplii, and the cladocera,

Daphnia galaeta mendotae are highly correlated with alkalinity. Seasonal variation has a minimal effect on the zooplankton community.

In conclusion, for reservoirs with distinct zones of differing water quality, separate zone models rather than a single model for the whole reservoir best describe patterns in the zooplankton community and its relationship to seasonal and physical and chemical factors.

Table 1 DCA model estimates of gradient lengths in standard deviation units (SD) of species turnover using Detrended Correspondence Analysis (DCA) for each of the four models.

	Gradient Length (SD)			
DCA Model	Axis 1	Axis 2	Axis 3	Axis 4
Whole Lake	2.654	2.261	1.871	1.518
Main Lake Body	2.027	1.734	1.720	0.934
Red River Arm	2.568	2.136	1.775	2.156
Washita River Arm	2.524	1.629	1.308	1.222

Table 2 Variance explained by each environmental factor retained after forward selection in the RDA and partial RDA based on all environmental factors (global approach). Each variable was statistically significant (p-value = 0.005).

Type of environmental factor	Variable	Variance explained (%)
Season	Spring	0.28
Zone	RRZ	0.04
	RRTZ	0.02
	MLZ	0.02
	WRZ	0.02
Physical-chemical	Nitrate	0.17
	Temperature	0.17
	Chlorophyll-a	0.13
	Sulfate	0.10
	Magnesium	0.09
	Potassium	0.08
	Alkalinity	0.06
	Nitrite	0.05
	Calcium	0.03
	Chloride	0.03
	Orthophosphate	0.03
	Secchi	0.02
	Total Suspended Solids	0.02
	Turbidity	0.02
	pH	0.01

Table 3 Variance decomposition of the effect of physical-chemical, seasonal, and zonal factors on the whole lake zooplankton community structure.

Source	*Inertia*	Variance Explained (%)
residual	0.481	48.1
shared *	0.286	28.6
pure physical-chemical	0.165	16.5
pure season	0.036	3.6
pure zone	0.032	3.2
Total	1.000	100.0

* shared variance among physical-chemical, zonal, and seasonal factors

Table 4 Variance explained by each environmental factor retained after forward selection and subsequent single removal of variables with VIF values >20 in the RDA and partial RDA based on season and physical and chemical factors only for theMain Lake model, Red River arm model and Washita River arm model.

Type of environmental factors	Variable	Main Lake Model		Red River Arm Model		Washita River Arm Model	
		Variance explained (%)	Significance P-value	Variance explained (%)	Significance P-value	Variance explained (%)	Significance P-value
Season	Spring	0.27	0.005	-	-	-	-
	Summer	-	-	0.30	0.005	0.33	0.005
Physical-chemical	Alkalinity	0.17	0.015	0.14	0.005	0.17	0.005
	Calcium	0.05	0.005	0.05	0.005	0.07	0.005
	Chlorophyll-a	0.11	0.005	0.14	0.005	0.22	0.005
	Chloride	-	-	0.10	0.005	-	-
	Dissolved Oxygen	0.15	0.005	-	-	-	-
	Potassium	0.19	0.045	0.12	0.050	0.18	0.005
	Turbidity	0.04	0.005	0.03	0.005	0.04	0.005
	Magnesium	0.15	0.005	0.06	0.010	0.18	0.005
	Sodium	0.03	0.005	-	-	0.06	0.005
	Nitrite	-	-	0.02	0.005	0.15	0.005
	Nitrate	0.23	0.005	-	-	0.23	0.010
	Orthophosphate	-	-	0.03	0.005	-	-
	pH	0.07	0.005	0.03	0.020	0.03	0.030
	Secchi	0.03	0.005	0.03	0.015	0.02	0.005
	Sulfate	-	-	0.07	0.005	-	-
	Temperature	-	-	0.17	0.005	0.22	0.005
	Total Phosphorus	0.02	0.020	-	-	-	-
	Total Suspended Solids	0.05	0.010	0.02	0.005	0.01	0.010

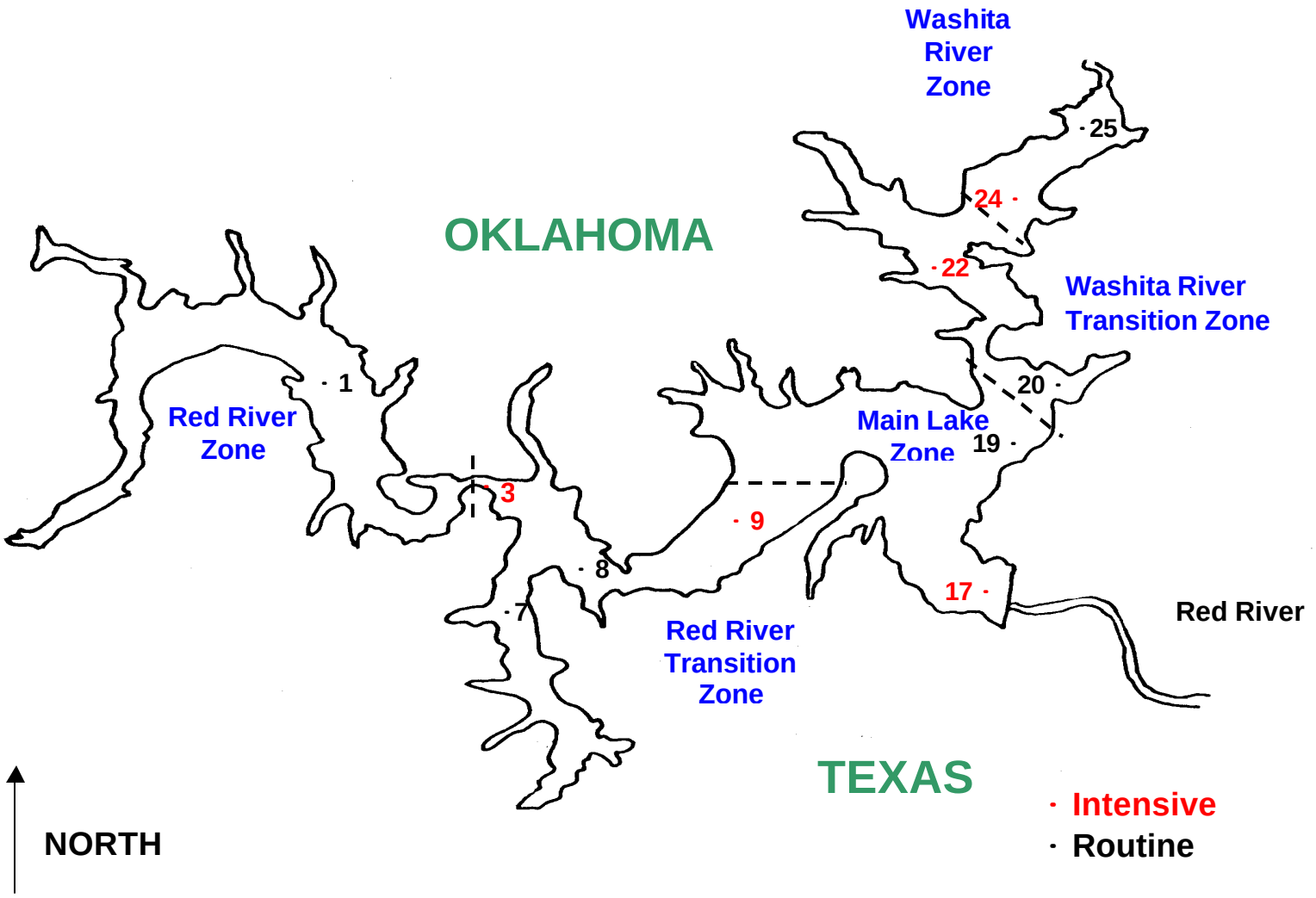

Figure 1 Map of Lake Texoma showing routine and intensive fixed station locations with each zone.

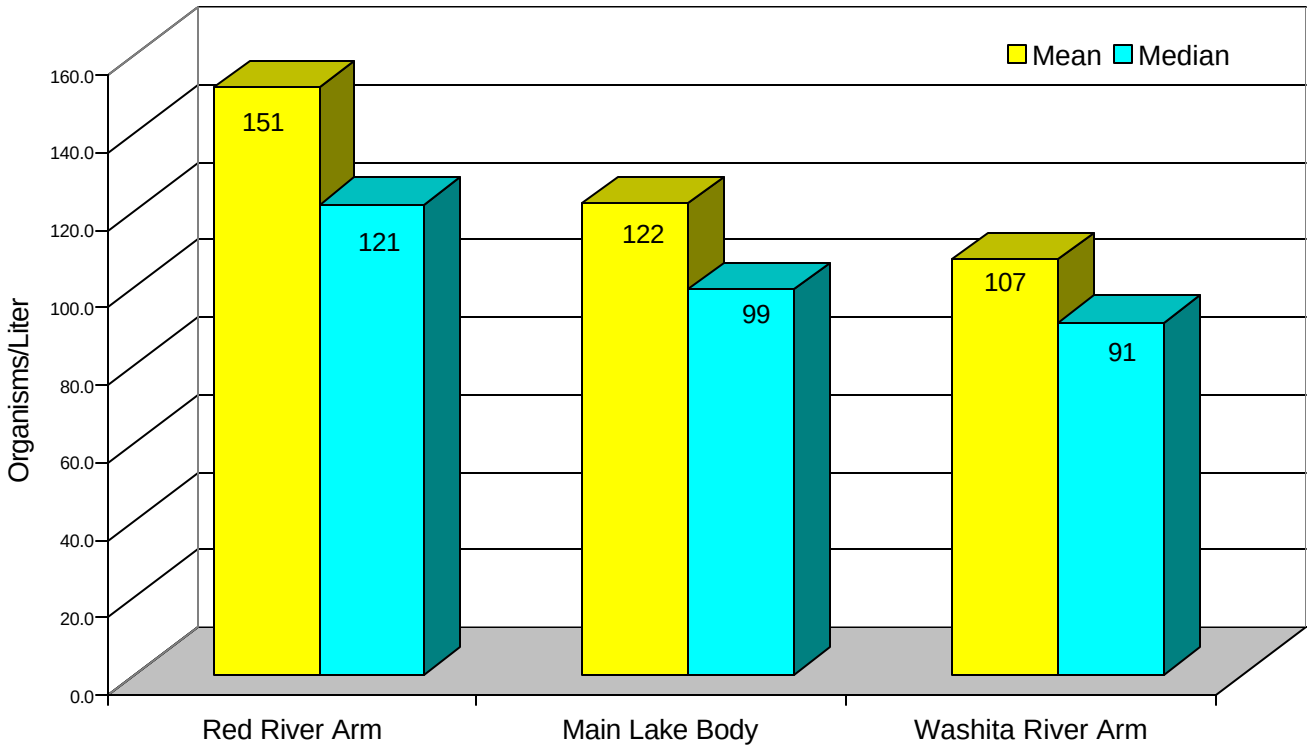

Figure 2 Comparison of zooplankton abundance (mean and median) between the Red River Arm, Main Lake Body, and Washita River Arm.

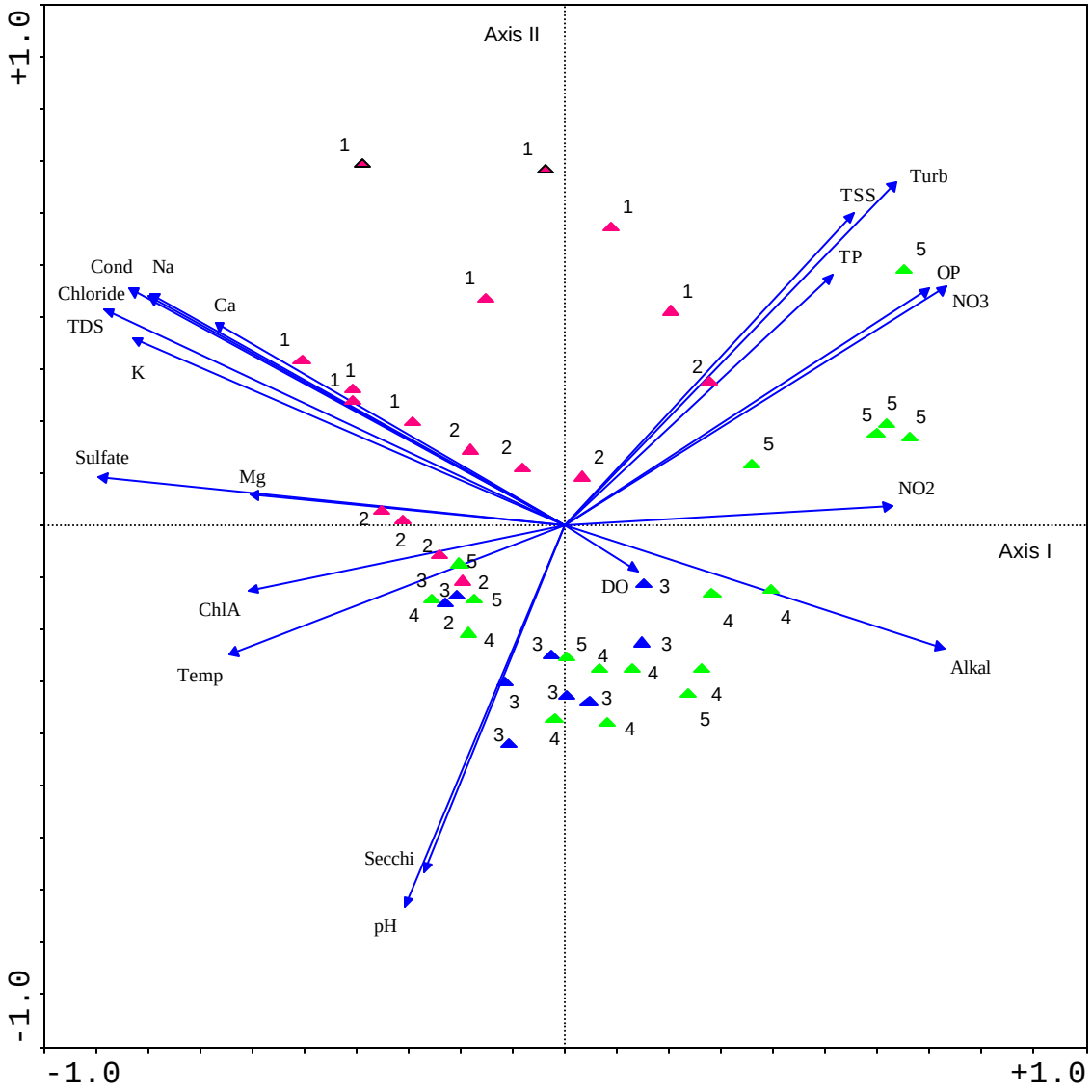

Figure 3 Relationship between the physical-chemical and field variables and lake zones. Correlation biplot displays 62.8% of the variance. Sites are displayed by triangles. Eigenvalues for the first three axes are 0.45, 0.18 and 0.11. Zones are symbolized as follows: Red River zone (1), Red River Transition zone (2), Main Lake body (3), Washita River Transition zone (4) and Washita River zone (5). Red symbols represent sites in the Red River arm, blue symbols represent sites in the Main Lake body and green symbols represent sites in the Washita River arm. Code for physical-chemical and field variables are given in Appendix 1.

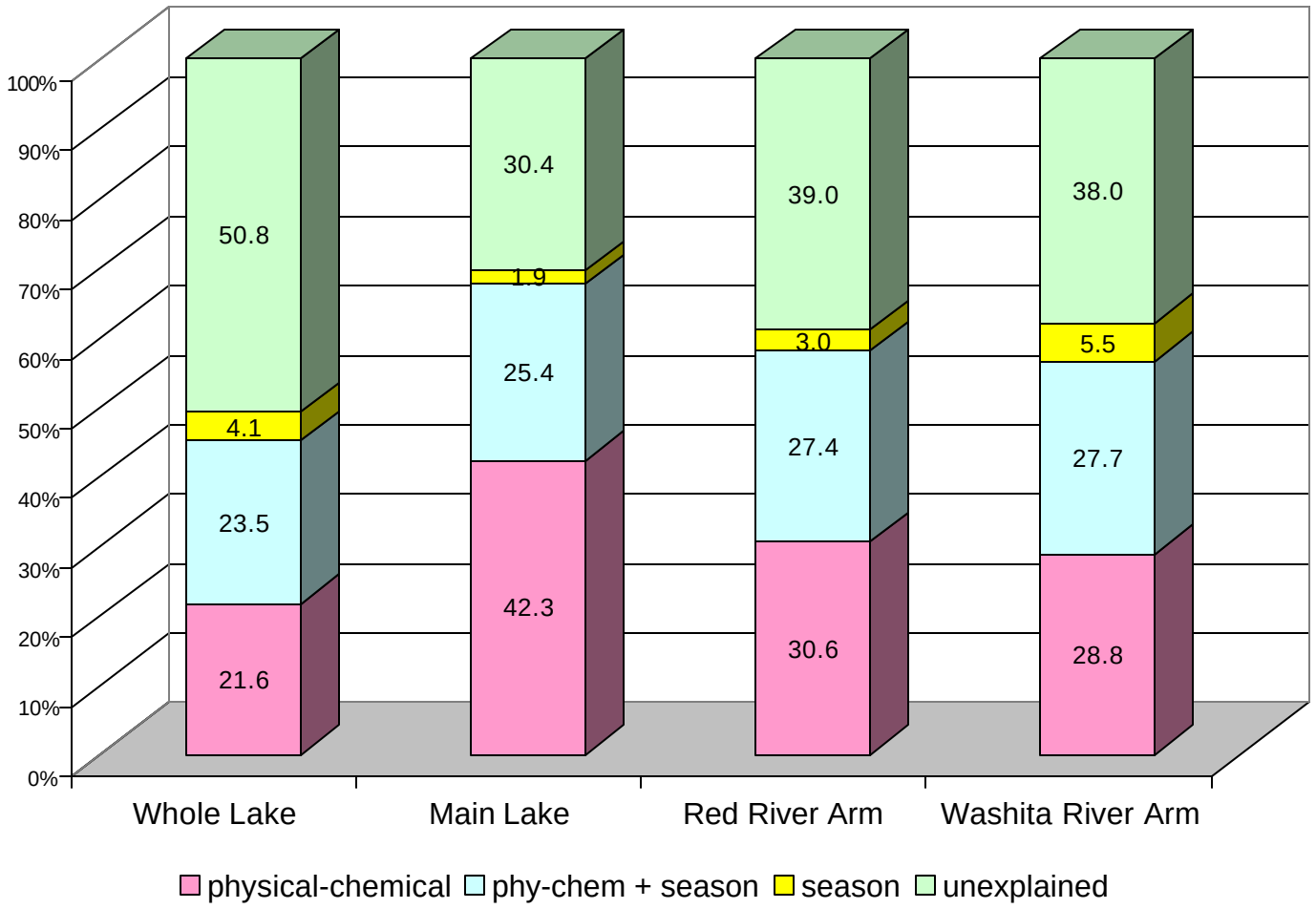

Figure 4 Variance decomposition of the effect of physical-chemical and seasonal factors on zooplankton community structure according to four independent models: the whole lake, Main Lake body, Red River arm and Washita River arm.

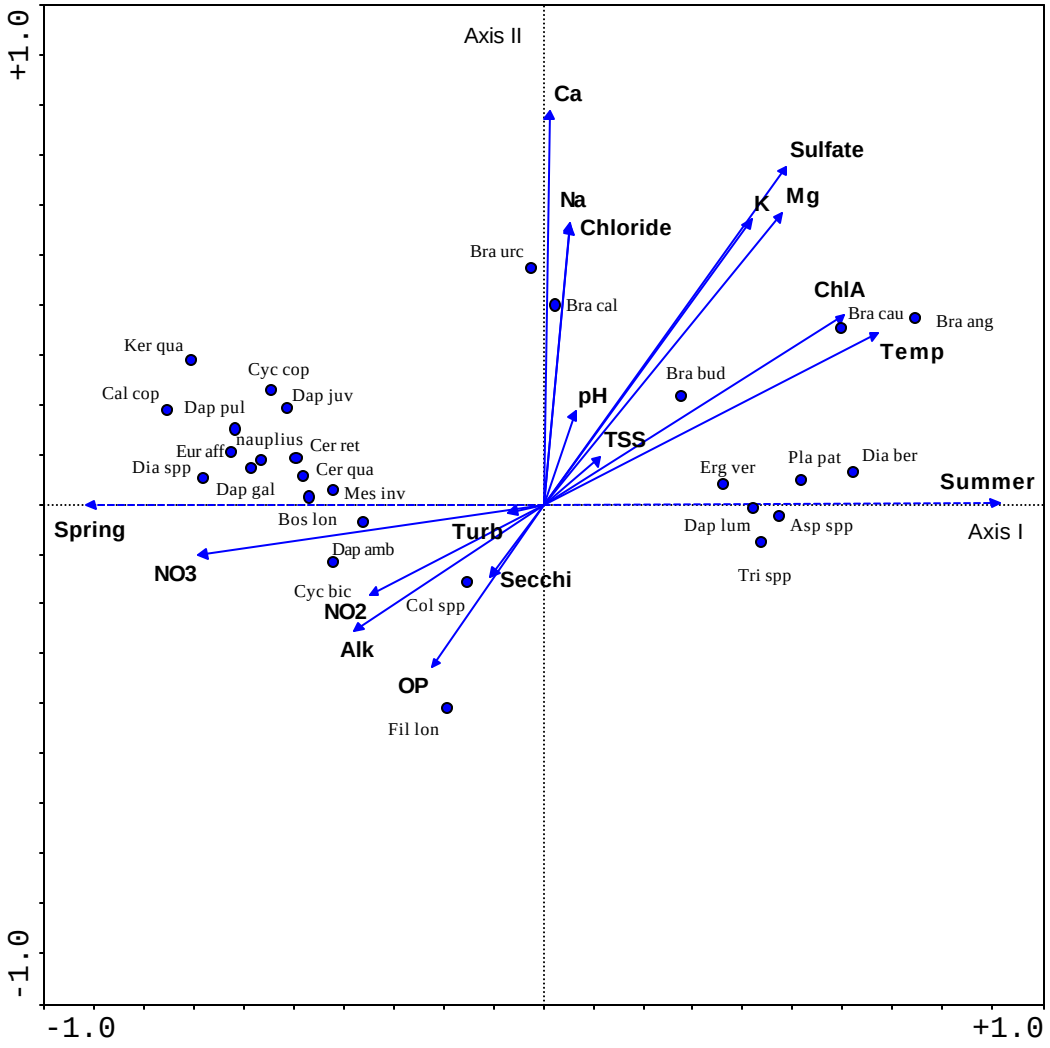

Figure 5 Whole lake RDA correlation biplot displays38% of the variance in the abundances and 76% of the variance in the fitted abundances. Quantitative environmental variables are indicated by solid arrows. Qualitative environmental variables are indicated by dashed arrows. Eigenvalues for the first three axes are 0.33, 0.05 and 0.03; the sum of all canonical eigenvalues is 0.49. The displayed taxa are selected on the basis that more than 30% of their variance is accounted by the diagram. Environmental variable codes are given in Appendix I and taxa codes are listed in Appendix II.

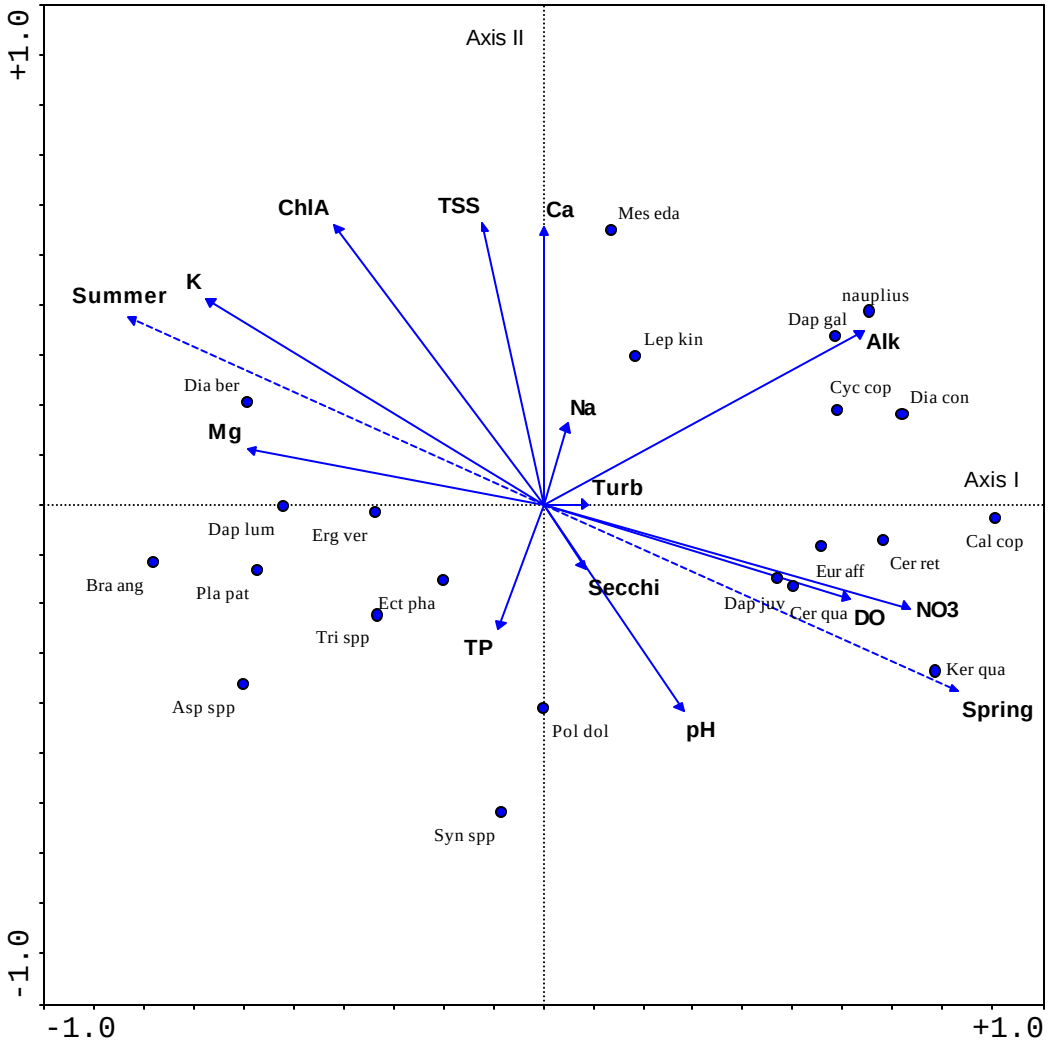

Figure 6 Main Lake body RDA correlation biplot displays 47% of the variance in the abundances and 67% of the variance in the fitted abundances. Quantitative environmental variables are indicated by solid arrows. Qualitative environmental variables are indicated by dashed arrows. Eigenvalues for the first three axes are 0.36, 0.11 and 0.10; the sum of all canonical eigenvalues is 0.70. The displayed taxa are selected on the basis that more than 30% of their variance is accounted by the diagram. Environmental variable codes are given in Appendix I and taxa codes are listed in Appendix II.

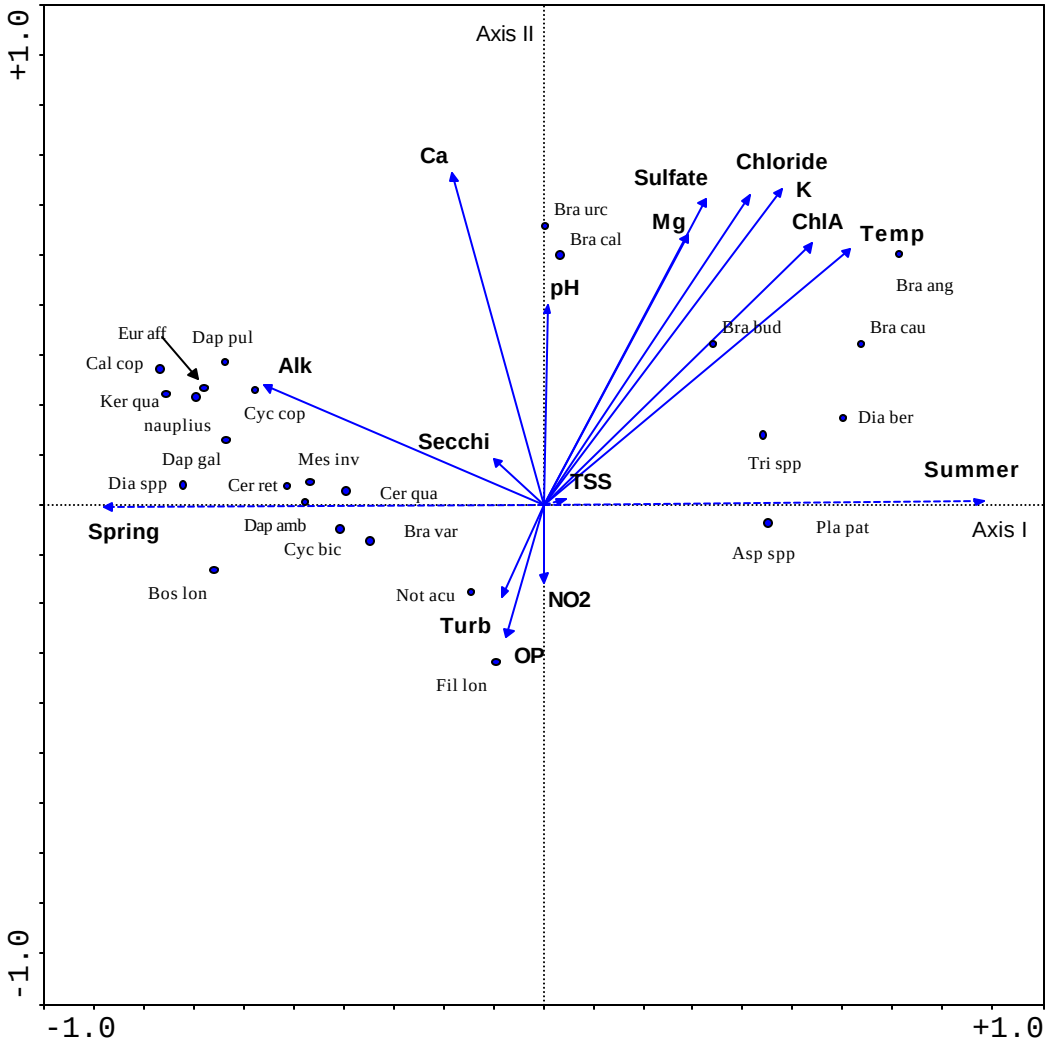

Figure 7 Red River arm RDA correlation biplot displays 46% of the variance in the abundances and 75% of the variance in the fitted abundances. Quantitative environmental variables are indicated by solid arrows. Qualitative environmental variables are indicated by dashed arrows. Eigenvalues for the first three axes are 0.37, 0.7 and 0.4; the sum of all canonical eigenvalues is 0.61. The displayed taxa are selected on the basis that more than 30% of their variance is accounted by the diagram. Environmental variable codes are given in Appendix 1 and taxa codes are listed in Appendix II.

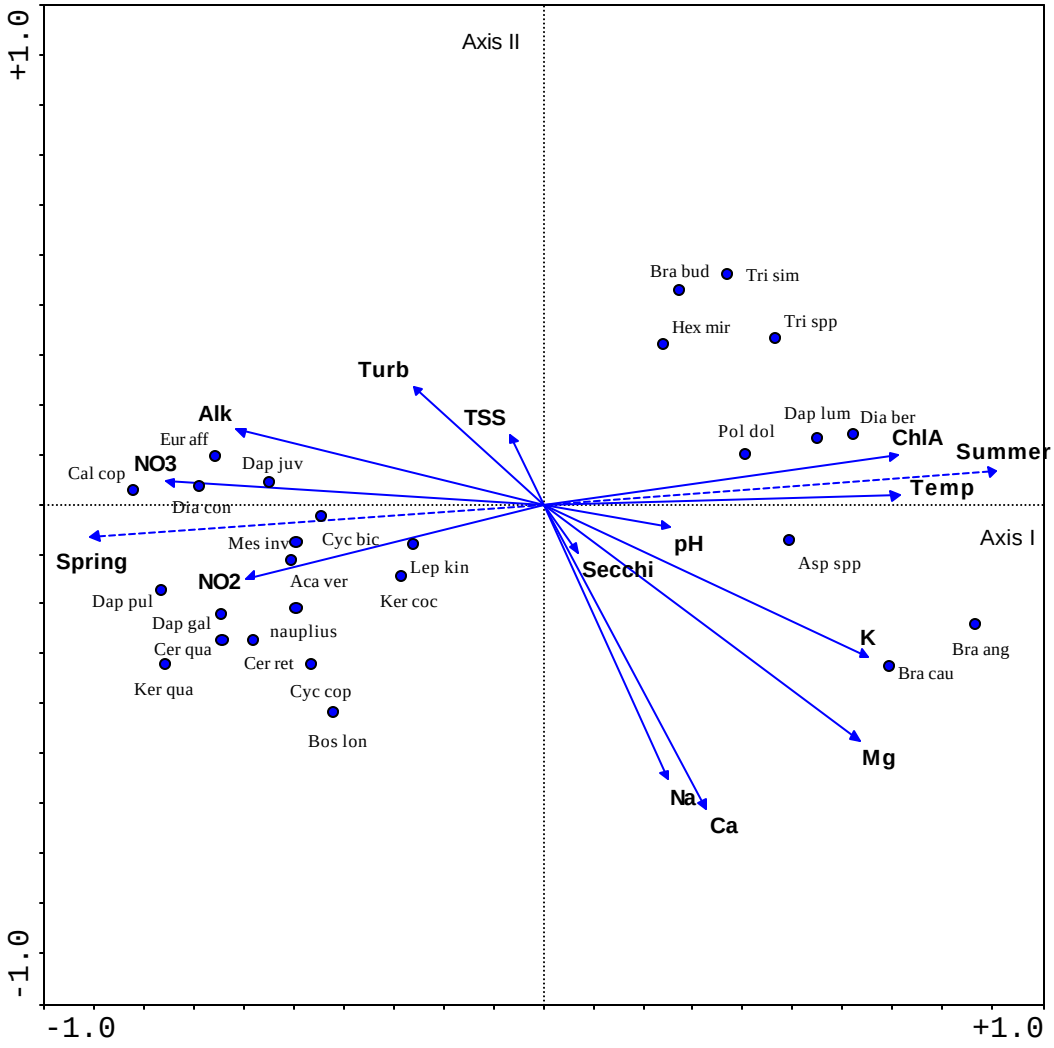

Figure 8 Washita River arm RDA correlation biplot displays 46% of the variance in the abundances and 75% of the variance in the fitted abundances. Quantitative environmental variables are indicated by solid arrows. Qualitative environmental variables are indicated by dashed arrows. Eigenvalues for the first three axes are 0.40, 0.07 and 0.04; the sum of all canonical eigenvalues is 0.62. The displayed taxa are selected on the basis that more than 30% of their variance is accounted by the diagram. Environmental variable codes are given in Appendix I and taxa codes are listed in Appendix II.

APPENDIX I

Appendix I Descriptive statistics for the physical-chemical variables by zone for the spring/summer 1997 Whole lake(n=405), Red River arm (n=162), Washita River arm (n=162), and Main Lake Body (n=81)

Zone	Mean	Median	Min	Max	Mean	Median	Min	Max
	Alkalinity (mg/L)*		Code:Alk		Magnesium (mg/L) *		Code: Mg	
Whole Lake	137	134	85	190	38	37	23	60
Red River Arm	121	122	85	150	39	39	23	54
Washita River Arm	153	151	115	190	39	36	28	60
Main Lake Body	135	136	119	158	37	36	31	45
	Calcium (mg/L)*		Code: Ca		Nitrite (mg/L)*		Code: NO_2	
Whole Lake	117	117	73	188	0.01	0.00	0.00	0.04
Red River Arm	129	128	90	188	0.00	0.00	0.00	0.03
Washita River Arm	109	106	73	154	0.01	0.00	0.00	0.04
Main Lake Body	112	112	80	134	0.01	0.00	0.00	0.03
	Chlorophyll-a (ug/L)*		Code: ChlA		Nitrate (mg/L)*		Code: NO_3	
Whole Lake	19.03	17.09	2.14	68.05	0.24	0.24	0.00	0.74
Red River Arm	20.94	20.16	3.20	68.05	0.24	0.27	0.00	0.74
Washita River Arm	18.72	16.32	2.14	51.41	0.26	0.25	0.00	0.74
Main Lake Body	15.86	12.82	2.14	50.20	0.18	0.14	0.00	0.55
	Chloride (mg/L)*				Orthophosphate (mg/L) *		Code: OP	
Whole Lake	248	249	24	562	0.01	0.01	0.00	0.04
Red River Arm	370	364	258	562	0.01	0.00	0.00	0.04
Washita River Arm	126	103	24	295	0.01	0.01	0.00	0.04
Main Lake Body	248	240	147	316	0.01	0.00	0.00	0.03
	Conductivity (uS/cm)		Code: Cond		pH*			
Whole Lake	1,574	1,520	677	3,130	8.11	8.12	7.55	8.54
Red River Arm	1,999	2,005	1,398	3,130	8.06	8.09	7.65	8.47
Washita River Arm	1,171	1,136	677	1,670	8.13	8.16	7.55	8.54
Main Lake Body	1,528	1,500	1,237	1,720	8.16	8.14	7.73	8.52
	Dissolved Oxygen (mg/L)*		Code: DO		Potassium (mg/L) *		Code: K	
Whole Lake	7.81	7.50	1.96	76.18	5.97	5.77	2.25	9.90
Red River Arm	7.73	7.36	1.96	76.18	6.98	6.84	4.50	9.90
Washita River Arm	7.87	7.62	2.66	73.65	5.04	4.87	2.25	7.65
Main Lake Body	7.83	7.98	4.21	12.17	5.80	5.57	4.16	7.60

Appendix I continued

Zone	Mean	Median	Min	Max	Mean	Median	Min	Max
	Secchi Disk Transparency (m) *				Total Dissolved Solids (mg/L) Code:TDS			
Whole Lake	0.90	0.85	0.15	3.45	1,061	1,052	491	1,870
Red River Arm	0.75	0.65	0.15	1.85	1,311	1,291	851	1,870
Washita River Arm	0.74	0.75	0.15	1.70	832	816	491	1,174
Main Lake Body	1.53	1.45	0.50	3.45	1,018	998	821	1,233
	Sodium (mg/L)*		Code: Na		Total Phosphorus (mg/L *)		Code: TP	
Whole Lake	164	167	13	348	0.05	0.05	0.01	0.17
Red River Arm	243	239	149	348	0.06	0.05	0.01	0.17
Washita River Arm	86	72	13	197	0.06	0.05	0.01	0.15
Main Lake Body	164	162	96	201	0.04	0.03	0.01	0.17
	Sulfate (mg/L)*				Total Suspended Solids (mg/L) Code: TSS			
Whole Lake	339	344	163	517	10.68	7.40	0.00	84.40
Red River Arm	373	373	212	517	10.34	7.70	0.00	55.20
Washita River Arm	312	294	163	507	15.49	9.10	0.00	84.40
Main Lake Body	326	316	259	420	1.72	0.00	0.00	6.10
	Temperature (^{o}C) *		Code: Temp		Turbidity (NTU) *		Code: Turb	
Whole Lake	22.42	23.96	9.96	31.48	11.01	6.30	1.70	79.50
Red River Arm	22.70	24.81	10.98	31.28	11.42	7.80	2.60	53.50
Washita River Arm	22.41	23.05	9.96	31.48	14.51	7.80	2.90	79.50
Main Lake Body	21.89	23.02	10.06	30.06	3.20	2.80	1.70	6.80

* independent variables retained in one or more RDA analyses.

APPENDIX Il

Appendix II Zooplankton taxa list and frequency (%) by zone in Lake Texoma during the spring and summer of 1997. Those with an "*" were omitted from all analyses because of their infrequent occurrence. Those with an "**" were omitted from independent zone analyses.

Taxa	Code	Whole Lake (n=405)	RRA (n=162)	MLZ (n=81)	WRA (n=162)
CLADOCERANS					
*Alona costata**	Alo cos	<1	<2	-	-
*A. rectangula **	Alo rec	2	1	1	4
B. longirostris	Bos lon	74	63	78	73
Ceriodaphnia quadrangula	Cer qua	28	10	28	34
C. reticulata	Cer ret	25	6	26	30
*Chydorus sphaericus**	Chy sph	4	1	-	1
Daphnia ambigua	Dap amb	25	40	16	23
*D. cawtaba **	Dap caw	<1	<2	<3	-
D. galaeta mendotae	Dap gal	56	31	67	64
*D. longiremis**	Dap lon	2	-	2	4
D. lumholtzi	Dap lum	28	28	26	30
D. parvula	Dap par	6	12	-	**6
D. pulex	Dap pul	46	43	36	50
D. juveniles	Dap juv	46	43	40	47
Diaphanosoma bergei	Dia ber	56	51	54	59
Leptodora kindti	Lep kin	14	**1	17	20
*Leydigia acanthocercoides**	Ley aca	<1	<2	-	<1
*Moina brachiata**	Moi bra	1	1	-	-
*M. micrura**	Moi mic	<1	<2	-	-
COPEPODS					
Calanoid					
Calanoid Copepods	Cal cop	79	74	74	79
Diaptomus sp.	Dia spp	59	49	58	66
Diaptomus connexus	Dia con	56	46	54	65
*D. saltillinis**	Dia sal	2	1	2	2
Eurytemora affinis	Eur aff	58	68	44	60
Cyclopoid					
Cyclopoid copepodid	Cyc cop	97	96	91	98
Acanthocyclops vernalis	Aca ver	47	56	46	67
Cyclops bicuspidatus	Cyc bic	26	19	35	30
Ectocyclops phaleratus	Ect pha	13	9	12	17
Ergasilus versicolor	Erg ver	19	12	23	20
Mesocyclops edax	Mes eda	51	31	67	59
M. inversus	Mes inv	26	23	23	28
copepod nauplii	nauplius	100	100	100	100

Appendix II continued

Taxa	Code	Whole Lake	RRA	MLZ	WRA
ROTIFERS					
Ascomorpha sp .	Asc spp	10	22	2	11
Asplanchna sp.	Asp spp	44	36	37	54
Brachionus angularis	Bra ang	65	88	47	65
*B. bidentata**	Bra bid	6	8	-	7
B. budapestinensis	Bra bud	16	37	**4	15
B. calyciflorus	Bra cal	25	64	**5	25
B. caudatus	Bra cau	34	49	9	41
*B. havanaensis**	Bra hav	7	3	2	11
*B. quadridentatus**	Bra qua	7	10	-	6
*B. rubens**	Bra rub	<1	1	-	<1
B. urceolaris	Bra urc	9	40	**1	**2
B. varibilis	Bra var	13	26	-	17
Collotheca sp .	Col spp	10	**5	12	13
Conochiloides dossarius	Con dos	11	**2	11	17
*Euchlanis alta**	Euc alt	<1	<1	-	<1
Filinia longiseta	Fil lon	20	15	11	32
*Gastropus sp.**	Gas spp	1	-	-	1
Hexarthra mira	Hex mir	14	4	**5	19
*Kellicottia bostoniensis**	Kel bos	1	-	2	2
Keratella cochlearis	Ker coc	87	79	79	96
K. quadrata f. testudo	Ker qua	80	84	75	75
*Lecane luna**	Lec lun	<1	<1	-	<1
*Lepadella patella**	Lep pat	<1	-	-	<1
*Monostyla spp.**	Mon spp	<1	-	-	<1
Notholca acuminata	Not acu	9	12	11	10
Platyias patulus	Pla pat	29	21	27	33
*P. quadricornis**	Pla qua	<1	<1	-	-
Polyarthra dolichoptera	Pol dol	64	53	48	77
P. euryptera	Pol eur	6	**7	**4	10
Pompholyx sp.	Pom spp	10	11	2**	14
Synchaeta sp.	Syn spp	63	67	48	98
*Testudinella sp.**	Tes spp	4	3	-	5
Trichocera spp.	Tri spp	29	25	16	48
T. lata	Tri lat	<1	-	-	**<1
T. multicrinis	Tri mul	6	**1	**1	14
T. similis	Tri sim	9	**1	**3	19
*Trichotria tetractis**	Tri tet	<1	-	-	<1

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ABNORMAL SPINE FORMATION IN *KERATELLA COCHLEARIS* IN LAKE TEXOMA

Introduction

Variations in posterior spine development in the rotifer *Keratella cochlearis* have been well documented, however, mention of the occurrence of individuals with deformed or aberrant posterior spines is lacking in the literature (Stemberger personal communication). In nature one can expect to find morphologically aberrant individuals occasionally, but when their presence increases dramatically, it raises questions as to why this is happening.

Normal posterior spines (Figure 2a), when present, are usually straight with a tapered end (Ruttner-Kolisko, 1974, Stemberger, 1979, Pennak 1989). Spine length is variable and thought to be a defensive mechanism to reduce predation from a specific taxonomic group, such as *Asplanchna* or predators belonging to different taxa and phyla, such as the cladoceran, *Bosmina longirostris* (Stemberger and Gilbert 1987, Conde-Porcuna and others 1993, Dieguez and others 1998). Several factors are known to cause variability in the posterior spine of normal *K. cochlearis* individuals. Environmental factors such as temperature, turbulence or food availability are also known to affect developmental growth in this species (Ruttner-Kolisko 1974, Bielanska-Granjner, 1995). Ruttner-Kolisko (1974) stated that forms with aberrant spine shape are

associated with high salinity waters. No further description or illustration is given to describe what was meant by aberrant or what constitutes high salinity.

In 1996, an intensive water quality monitoring study was begun to establish base-line physical-chemical-biological data for Lake Texoma. The data could be used to examine the effectiveness of established and future U.S. Army Corps of Engineers projects aimed at reducing the input of chlorides into the Red River and to examine the relationships between chloride concentration, turbidity and phytoplankton at various locations in Lake Texoma. For this study data were collected from August 1996 through September 1997. In March 1999, a second study was begun to examine algal productivity dynamics in Lake Texoma. During enumeration of the zooplankton for these studies, abnormalities in the rotifer, *K. cochlearis* were observed with increasing frequency in the second study. Rare occurrences of aberrant *K. cochlearis* were first observed during late spring of 1997 mainly because of their unusual morphology. In these few observations, the posterior spine terminated in a horizontal bar-like structure perpendicular to the vertical portion of the spine (Figure 2e). During enumeration of the 1999 spring samples, numerous occurrences of these same deformities and other morphological variations were observed (Figure 2). The purpose of this research is to examine these deformities and the environmental conditions present at the time of their occurrence.

Methods

Zooplankton samples were collected from 16 stations during the 1996-97 study and 11 stations during the 1999 study on Lake Texoma, from August 1996 through September 1997 and from March 1999 through August 1999. Figure 1 shows the sampling locations for each study, some of which were the same in both studies. Three replicate samples were collected from each station during both studies with the following exception. Ten replicate samples were collected from stations 3, 9, 17, 22 and 24 during the 1996-97 study only. Samples were collected monthly except as follows: 1) samples were not collected for the months of October, November and February because the historical data shows little change in physical-chemical parameters during the winter months (Atkinson and others 1996), and 2) samples were collected twice monthly for May and June when physical-chemical and biological changes were most dynamic.

Zooplankton samples were collected by a ten meter vertical tow using a No. 20 nylon plankton net fitted with a Wisconsin bucket (80 micron mesh) for concentrating samples in the field. For stations less than 11 meters in depth, vertical tows were taken from one meter above the bottom to the surface. Station depth was determined using sonar technology. Contents of the Wisconsin bucket were thoroughly washed with distilled water into a prelabeled 125 ml polyethylene sample bottle and preserved with Lugols solution (Wetzel and Likens 1979).

Zooplankton were enumerated and identified to the lowest possible taxon following Edmondson (1959), Stemberger (1979), Pennak (1989). A minimum of

170 to 200 organisms were counted per sample (EPA 1998). Counts were converted to organisms per liter of lake water.

Temperature (^{o}C), dissolved oxygen (mg/L), conductivity (µS/cm) and pH (standard units) were measured with a Hydrolab (H20) datasonde at two meter intervals beginning one meter below the surface and ending one meter above the bottom. In the 1997 study, triplicate whole water samples were pumped from one meter below the surface for 15 water chemistry analyses (alkalinity, calcium, chlorophyll-a, chloride, magnesium, nitrate, nitrite, orthophosphate, potassium, sodium, sulfate, total dissolved solids, total phosphorus, total suspended solids and turbidity). TRAC Labs of Denton, Texas performed the water chemistry analyses using APHA approved methods. Chlorophyll-a was analyzed at the University of North Texas. Water chemistry analyses performed in the 1999 study include alkalinity, ammonium, chloride, chlorophyll-a, nitrate, nitrite, total Kjeldahl nitrogen, orthophosphate, salinity, sulfate, and total suspended solids. For this study, Mantech Environmental Research Services Corp., Ada, Oklahoma performed the water chemistry analyses, except for turbidity and chlorophyll-a, which were analyzed at the University of North Texas. For comparison, salinity was calculated for both studies from the Hydrolab conductivity measurements using the conversion formula recommended by Hydrolab, Inc. for use with their instrument.

Results

Several unusual anomalies were observed in the posterior spine of *Keratella cochlearis,* during the spring of 1997 and 1999 (Figure 2). Although *K. cochlearis* was present throughout the reservoir during both studies, deformed specimens were observed primarily in the Red River arm and main lake body and a single station (20) in the Washita River arm. Stations were located both in the main channel (stations 3 and 9), as well as, in some of the smaller tributaries (stations 4, 7,13, 15 and 20). Abnormalities were observed from stations 9 and 7 from both studies. Deformed spines ranged from slight crookedness to sharp angular bends some with hook-like extensions (Figure 2).

The occurrence of deformed *K. cochlearis* increased considerably in 1999 from that of 1997. In 1997, the deformity was found at most in 1.20% of the samples (n=83) and 6.67% of the stations (n=15) during May and June compared to 51.52% of the samples (n=33) and 63.64% (n=11) of the stations in 1999. Abnormal organisms began to show up in March 1999 and declined by the end of May 1999 (Figure 3). No abnormal individuals were observed from the June 1999 and subsequent samples. Although the mean percent deformed was generally less than 10%, on several occasions it was greater, reaching as high as 25.86% at station 7 in March of 1999 (Figure 3).

Abnormal individuals were associated with lake zones with high conductivity (1615 to 2493 *u*S/cm) and salinity (0.3 to 2.9 g/L) and stations with low turbidity ((3.2 - 6.2 NTU) as compared to the remainder of the stations (Table 1). Lake Texoma has a pronounced conductivity and turbidity gradient resulting from natural salt seeps in the Red River watershed. Deformed individuals were

primarily associated with the Red River arm and main lake body where the mean conductivity values (2493 to1984 *u*S/cm) and salinity concentrations (2.9 to 1.1 g/L) were the greatest. Deformed individuals were only found at station 20 in the Washita River arm, which had a greater mean conductivity (1615 *u*S/cm) and salinity (0.3 g/L) than all of the stations in this arm of Lake Texoma (1317 *u*S/cm, and 0.1g/L, respectively). Mean salinity concentrations in the Red River arm were much greater during the 1999 study (4.0 g/L) compared to those for the 1996-97 study (0.9 g/L). Within each zone, deformed individuals were associated with stations with lower mean turbidity than the other stations in the zone. For example, the mean turbidity for the Red River arm for all stations was10 NTU and deformed individuals were found at stations whose mean turbidity was 6.2 NTU. This same trend also occurs in the Washita River arm (7.7 and 4.0 NTU, respectively) and main lake body (4.4 and 3.2 NTU, respectively). Mean temperature, pH, and dissolved oxygen were showed little variability throughout the lake during both studies. There is no apparent relationship between these three variables and presence of deformed individuals.

Discussion

Keratella. cochlearis is quite common and widespread throughout Lake Texoma (Crist 1980, Atkinson and others 1999) but the presence of deformed individuals rose dramatically during the 1999 study representing on average 6.79% of the individuals at certain locations. On one occasion (March 1999 station 7) 25.86% of the individuals were deformed. Other researchers who have

identified zooplankton from Lake Texoma in the past have not observed such deformities (personal communication Threlkeld, Dirnberger, and Work). Richard Stemberger and William Cody (personal communication) have seen forms like this from other reservoirs but only rarely.

Deformed *K. cochlearis* in Lake Texoma appear to be associated with salinity, conductivity, turbidly and season. Conductivity and salinity are greater in the Red River arm and main lake body due to the inflow from the highly saline Red River. Abnormal individuals were observed at most of the stations in this part of Lake Texoma. Turbidity varies across the whole lake, as well as, within each lake zone. Within a given zone, abnormal individuals were observed at stations with lower turbidity than the zonal average. Anomalies were only observed during the spring season during May and June in 1997 and March through May in 1999, suggesting this may be a seasonal or temperature related event. Ruttner-Kolisko mentioned the presence of *K. cochlearis* with aberrant spine formation occurring in highly saline waters; however, no mention was given as to what salt concentration was considered highly saline. Salinity concentrations in the Red River arm were four times greater during the 1999 study when increased deformities were observed suggesting this may be a cause. Increased salinity concentrations in the Red River arm are the result of reduced flows due to the drought conditions occurring during the 1999 study. *Abnormal K. cochlearis* was not observed in the upper Red River arm, but more in the transition zone and main lake body. Highest numbers of abnormal *K.*

cochlearis were observed at station 7 in the Big Mineral arm (mean salinity 2.5 g/L).

Environmental factors such as temperature, food availability and water turbulence have been shown to contribute to allometric growth in *K. cochlearis*. The presence of predatory rotifers and some cladocera have also been shown to affect posterior spine length in this organism. Although measures for environmental factors were recorded, as well as information on the abundance of other zooplankton, no causal relationships can be drawn between these and the presence of abnormal individuals in this study. Continued annual collections during 2000 may help to determine if the increased occurrence of abnormal individuals is an isolated event or possibly associated with drought conditions such as those experienced in north Texas during the past two years.

Laboratory studies are needed to determine if the abnormality is genetic or environmentally induced in *K. cochlearis*. Examination of progeny from several generations of laboratory cultured gravid aberrant individuals may help determine if the abnormal trait is genetic. If the abnormal trait can be induced in normal cultured individuals exposed to different levels of salinity, temperature, conductivity and turbidity, then the trait is not genetic, but rather a response to an environmental factor.

Table 1 Selected mean physical parameters (surface) for all stations and those stations where deformed *K. cochlearis* were found for zones of Lake Texoma. Standard deviations are given in parentheses. The number of stations in a zone is shown in brackets. Calculations are for time the period in which deformities were observed for each study (second May trip and first June trip for the 1997 study; March and both trips in May for the 1999 study).

Lake Zone	Temp (^{0} C)	pH (S)	Cond (uS/cm)	Salinity (g/L)**	DO (mg/L)	Turbidity (NTU)
All Stations						
1997						
Red River [5]	23.56 (2.4)	8.18 (0.2)	2029 (247)	0.9 (0.5)	8.36 (2.0)	7.8 (4.5)*
1999						
Red River [5]	19.94 (5.6)	7.97 (0.1)	2705 (660)	4.0 (5.1)	7.98 (1.0)	10.0 (9.6)
Main Lake [3]	20.26 (3.6)	8.08 (0.3)	1990 (489)	1.1 (1.1)	7.97 (0.6)	4.4 (4.2)
Washita River [3]	20.63 (5.2)	8.17 (0.2)	1317 (257)	0.2 (0.1)	7.92 (0.6)	7.7 (4.8)
Stations with deformed *K. cochlearis*						
1997						
Red River [2]	22.89 (4.8)	8.20 (0.3)	1993 (123)	0.8 (0.2)	8.66 (3.2)	6.2 (1.5)*
1999						
Red River [4]	21.59 (4.7)	8.06 (0.2)	2493 (525)	2.9 (2.3)	8.08 (1.4)	6.2 (3.0)
Main Lake [2]	23.07 (0.9)	8.05 (0.6)	1984 (623)	1.1 (1.4)	7.81 (0.7)	3.2 (1.6)
Washita River [1]	23.10 (2.7)	8.34 (0.1)	1615 (21)	0.3 (0.0)	7.67 (0.5)	4.0 (0.6)

*Turbidity was measured in the lab during the 1997 study and in the field during the 1999 study.
** Salinity calculated from Hydrolab conductivity measurements using the formula provided in the Hydrolab Water Quality Manual (1995).

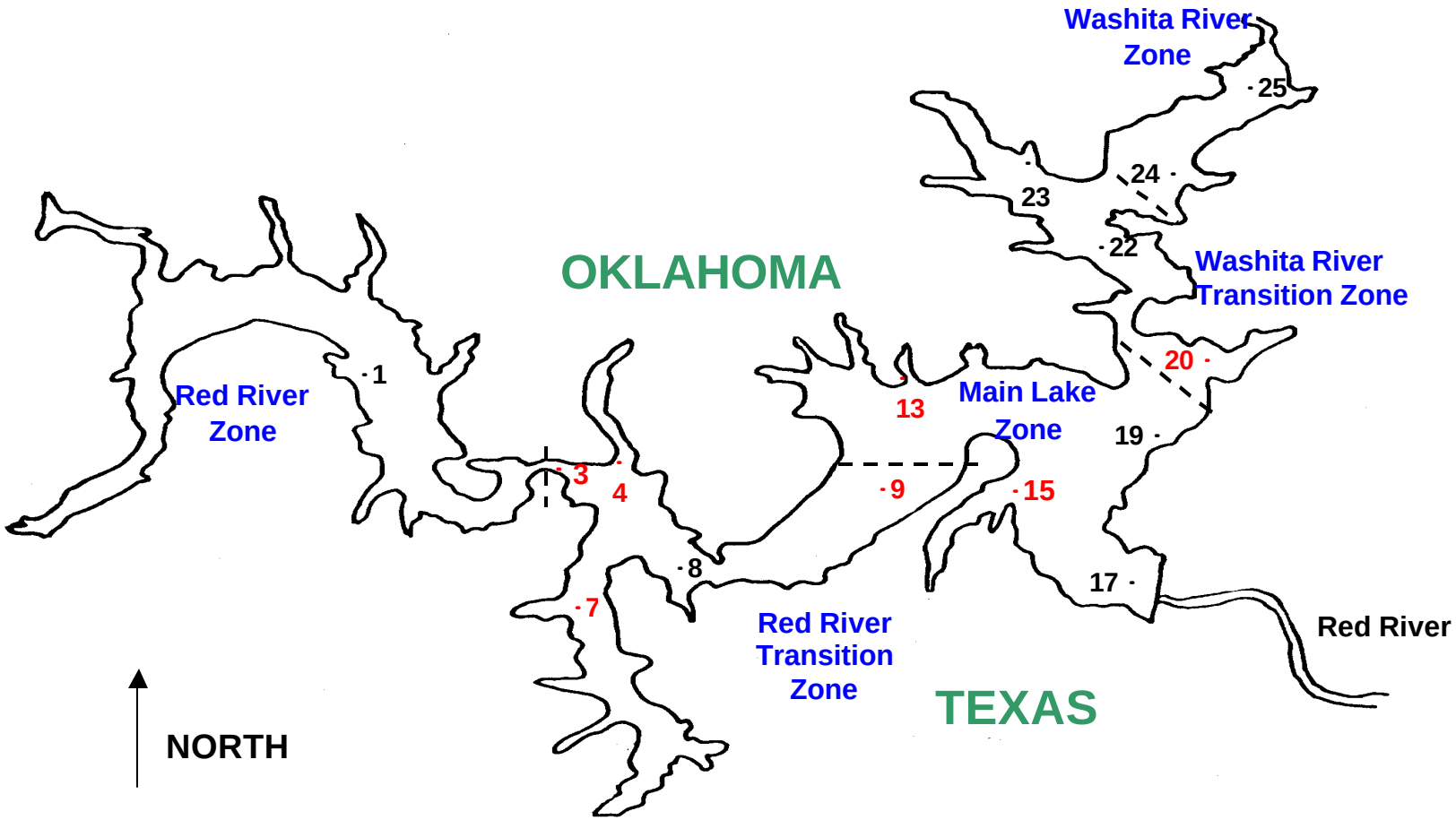

Figure 1. Map of Lake Texoma showing sampling stations for 1996-97 and 1999 studies. Stations overlapping both studies include (1, 3, 7, 9, 17, 20, 22, 25). Stations where abnormal K. cochlearis were observed are shown in red.

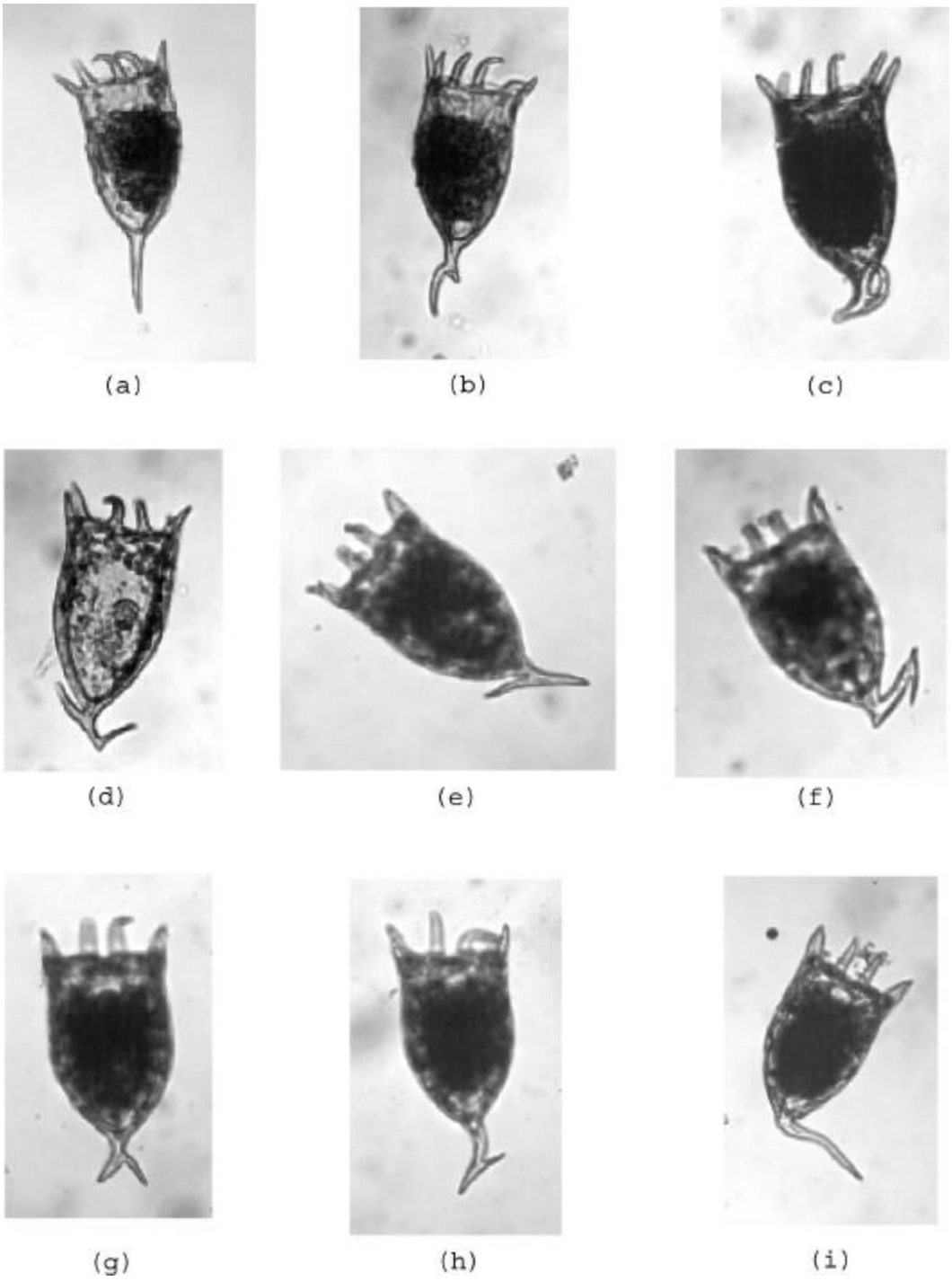

Figure 2 Normal posterior spine development (a) and aberrant variations (b-i) in the rotifer, *Keratella cochlearis*.

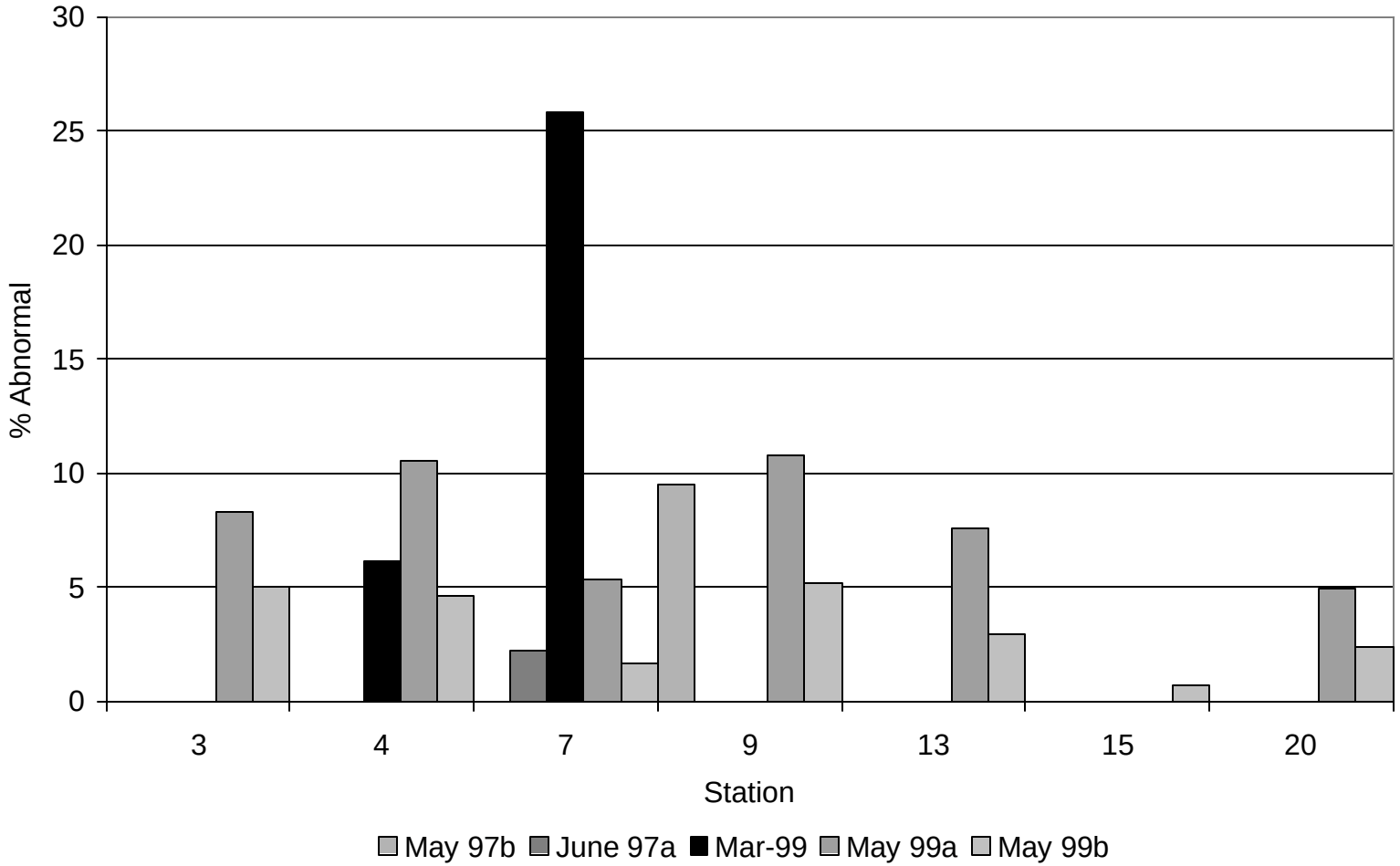

Figure 3 Percentage of abnormal *Keratella cochlearis* by station for the 1996-97 and 1999 studies.

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CONSIDERATION OF POWER, SAMPLE SIZE, AND TAXONOMIC RESOLUTION IN ZOOPLANKTON SAMPLING DESIGNS

Introduction

The literature is replete with examples of zooplankton sampling designs for which 3 replicate samples were collected from each of several sites (Crist 1980, Makarewicz and Lewis 1979) or a single sample was collected from several lakes or reservoirs in a region (Taub and Wiseman 1998) over a specified sampling period. Zooplankton are then identified and enumerated to either genus or species, however, abundance is reported for major groups of zooplankton such as the cladocera, cyclopoids, rotifers and nauplii (Harman and others. 1995). From a statistical point of view, the analyses performed on data from these studies are often lacking in power (the ability to detect a small percent difference in the observed mean abundance) making them relatively insensitive to detecting true shifts in the population mean especially at lower levels of taxonomic resolution such as genus or species.

The purpose of this research is to demonstrate the effect of sample size (number of replicates collected at each sampling site) and taxonomic resolution on the sensitivity of a zooplankton study to detect shifts in the population mean using the traditional sampling methods described above. Although basic statistic courses emphasize that power increases with sample size, they do not discuss how this applies to zooplankton sampling designs and its relationship to taxonomic resolution.

Methods

Zooplankton samples were collected from 16 stations on Lake Texoma, a multipurpose reservoir located on the Red River between Texas and Oklahoma, from August 1996 through September 1997 (Figure 1). Eleven sampling stations were classified as routine stations from which 3 replicate zooplankton samples were collected. Five stations were classified as intensive stations from which 10 replicate zooplankton samples were collected. Only data from the intensive stations were used in this analysis. Samples were collected monthly except as follows: 1) samples were not collected for the months of October and December 1996 and February 1997 because the historical data shows little change in physical-chemical parameters during the winter months (Atkinson and others 1996), and 2) samples were collected twice monthly for May and June when physical-chemical and biological changes were most dynamic.

Zooplankton samples were collected by a ten-meter vertical tow using a No. 20 nylon plankton net fitted with a Wisconsin bucket (80 micron mesh) for concentrating samples in the field. For stations less than eleven meters in depth, vertical tows were taken from one meter off the bottom. Station depth was determined using sonar technology. Contents of the Wisconsin bucket were thoroughly washed with distilled water into a prelabeled 125 ml polyethylene sample collection jar and preserved with Lugols solution (Wetzel and Likens 1979).

Zooplankton were identified and enumerated to the lowest possible taxon following Edmondson (1959), Stemberger (1979) and (Pennak 1989). A minimum of 170 to 200 organisms were counted per sample (EPA 1998). Counts were converted to organisms per liter of lake water.

Statistical Analyses

Count data from the intensive stations (3, 9, 17, 22, and 24) were used to estimate the relationship between sample size, power or sensitivity of the analysis to detect a statistically significant difference in the mean, and taxonomic resolution for the August 1996, January 1997 and May 1997 sampling trips. Taxonomic resolution refers to the levels of classification; Kingdom being the highest, less resolution classification and species the lowest, most resolution classification. These months were chosen because they represent different seasons and different densities of zooplankton. Zooplankton abundance (org/L) was calculated for each level of taxonomic resolution (Kingdom, Phylum, Class, Order, Family, Genus, and Species) using 10 replicate samples. Another data set then was created using a random number table to remove 3 replicate samples from each intensive station leaving 7 replicate samples. Two additional data sets were then created in the same fashion, one with 5 replicate samples and one with 3 replicate samples. The five data sets were analyzed using a log-linear regression model in which the dispersion parameter was estimated from the data rather than set equal to 1 as in Poisson models (Ammann and others 1997). Alpha and beta were set at 0.10. Power and sample sizes were

determined at each taxonomic resolution as described in Ammann and others (1997). The statistical functions necessary to perform these analyses were developed by Larry Ammann (University of Texas at Dallas) for use with the statistical package S-PLUS. Table 2 shows the number of samples needed to detect a 10%, 20%, 30%, 40% and 50% decrease in the observed mean organisms per liter for each taxonomic resolution for the August 1996 count data.

Results

The number of organisms counted per sample for samples collected at the intensive stations (n=150) during August 1996, January 1997 and May 1997 ranged from 172 to 664 individuals. For 97% of the samples, greater than 190 individuals were counted per sample. Considering all samples independent of station and time (n=1076), greater than 190 individuals were counted in 96% of the samples.

The power analysis results for August 1996 (Table 1) showed that the percent observable decrease from the mean of 230 org/L at the Kingdom level was 27.5% based on 3 replicate samples. Increasing the number of replicate samples to 10 at the same taxonomic level reduced the percent observable decrease from the mean of 207.13 org/L to 13.7%. The power or sensitivity of the analysis to detect a statistically significant difference in the mean doubled with 10 replicates. Therefore, more power was gained as the number of replicates increased. Similar results were observed for the January 1997 and May 1997 analyses (Table 1).

Next, the affect of power on taxonomic resolution was examined. The level of analysis (taxonomic resolution) was divided into metrics based on taxonomic classification with Kingdom being the highest or less resolute metric and Genus the lowest or most resolute metric. Considering the above example (August 1996) using 3 replicates, the percent observable decrease from the mean of 230.69 org/L at the Kingdom level was 27.5% compared to 56.64% observable decrease from the average mean of 18.81 org/L at the Genus level. Using the January 1997 data, the percent observable decrease from the mean of 286.15 org/L at the Kingdom level was 13.30% compared to 40.12% observable decrease from the average mean of 21.71 org/L at the Genus level. Therefore, the power to detect statistically significant differences in the mean was much reduced at the lower taxonomic resolution of Genus. The same pattern was observed for the May 1997 analyses (Table 1).

The results for the August 1996 analysis described above are further demonstrated in Figure 2. The bars represent the average number of org/L shown on the left y-axis for each treatment (number of replicate samples: 3, 5, 7 or 10) and metric. The lines represent the average percent observable decrease in means shown on the right y-axis. In every situation, the average percent observable decrease becomes smaller as more samples are collected increasing the power or sensitivity of the analysis. For the August 1996 analysis, the average percent observable decrease for 3, 5, 7 and 10 replicates for the metrics Kingdom through Order ranged from 13.7% to 29.8% compared to 33.26% to

56.64% for the Family and Genus metrics. Therefore, the trend in power for 3, 5, 7, and 10 replicates were similar and the percent range small for the metrics Kingdom through Order. Power decreased considerably for the Family and Genus metrics and the range was greater among replicates. The percent observable decrease in the mean number of organisms per liter is similar for 10 replicates at the Family level (33.26%) and 3 replicates at the Order level (29.8%). Similar patterns were observed for the January 1997 (19.47% and 20.47%, respectively) and May 1997 (31.86% and 34.30%, respectively) analyses.

The relationship between mean zooplankton density and power was also examined. For mean densities less than 60 org/L, the percent observable decrease ranges from 12.9% to 92.6% compared to the range of 9.4% to 34% for mean densities greater than 60 org/L (Figure 3). Although, mean density does affect power with respect to the full range of taxonomic resolution, it does not affect power at the individual taxonomic levels. For example, for the Kingdom metric using the August 1996 data (Table 1), the mean density ranges from 207.13 org/L for 10 replicate samples to 230.69 org/L for 3 replicate samples. At the same time, the percent observable decrease more than doubles over the same range from 13.7% for 10 replicate samples to 27.50% for 3 replicate samples. It is the increased number of replicate samples that increases the power rather than the mean density. A similar pattern can be observed in Table 1 for each taxonomic metric regardless of sampling month.

The number of samples required to detect a specific percent reduction in mean increases with the level of taxonomic resolution (Table 2). The information in this table produced from the analysis of the August 1996 taxa count data for the intensive stations each having 10 replicate samples is representative of that observed for the January 1997 and May 1997 analyses. A log linear model was used with beta and alpha set at 0.10. At the Kingdom level of classification, one replicate sample would be required to detect as little as a 20% reduction in the mean of 207.13 org/L. In order to detect a 10% reduction in the same mean value, the number of samples required increases to 4. At the Genus level of classification, 2 replicate samples would be required to detect a 50% reduction in the mean value of 11.95 *Diaphanosoma*/L. In order to detect a 10% reduction in the same mean, the number of replicate samples increases to over 200. Therefore, as the level of classification becomes more resolute, greater numbers of samples are required to detect a smaller and smaller percent reduction in the mean value. Exceptions to this trend occur for the most dominant genera such as the rotifer genera *Platyias* and *Brachionus* in this example. This knowledge is important especially for studies where only a few samples are collected and zooplankton are analyzed at the genus level of classification resulting in a sampling design that is relatively insensitive to detect small percent reductions in the mean value, especially for the non-dominant genera.

Discussion

Power, number of replicates, and taxonomic resolution are three important factors to be considered when choosing a sampling design. This study demonstrates that the ability to detect a certain percent decrease in the mean number of organisms (power) is directly related to taxonomic resolution and number of replicate samples collected. Three conclusions can be drawn from this demonstration. 1) At any given taxonomic metric, power increases with an increase in number of replicate samples collected (Figure 2). For example, for the Kingdom metric, the power for 3 replicate samples is 27.5% compared to 13.70% for 10 replicate samples. This means that the percent observable decrease in the mean organisms per liter is much smaller for 10 replicate samples making the analysis more sensitive to mean differences than that for 3 replicate samples. This trend is apparent for each taxonomic metric. 2) The power associated with a set number of replicate samples decreases with an increase in taxonomic resolution (Table 1). For example, using the August 1996 data and 3 replicate samples, the percent observable decrease in mean organisms per liter increases with each taxonomic metric from 27.5% to 29.30% to 29.30% to 50.46 %to 56.64% respectively for the metrics, Kingdom, Phylum, Class Order, Family and Genus. This trend is observed for each group of replicate samples and for each sampling trip analyzed. 3) The range of power associated with a set number of replicate samples can be divided into 2 groups of metrics: 1) Kingdom, Phylum, Class and Order and 2) Family and Genus (Figure 2). For each group, the range of power associated with a replicate

sample group is small and only a small increase in power is gained from one taxonomic metric to another. However, there are considerable differences in power between the two groups with the more resolute group being the least sensitive in detecting differences in the observed mean of the population. A similarity in power between the two groups occurs with 10 replicate samples analyzed at the Family or Genus metric and 3 replicate samples analyzed at the Kingdom, Phylum, Class or Order metrics. Analyses at less resolute taxonomic metrics are more sensitive to detecting smaller percent decreases in mean number of organisms per liter than those analyzed at the Family or Genus metric. Therefore, from a power perspective, it is more economical to process 3 replicate samples to a less resolute metric than 10 replicate samples to a more resolute metric.

Power in analyses is important because it measures the sensitivity of the analysis to detect differences in the mean abundance of organisms from several locations. Historically, for most studies only a few samples are collected and an analysis of variance on mean organisms per liter is used to determine if the stations are significantly different from one another. For taxonomic resolutions lower than order and for sample sizes of 3 or less (Table 2), most often the ANOVA will not be able to detect even a 50% decrease in the observable mean abundance. Exceptions to this occurs for dominant zooplankton classifications such as the Families Bosminidae, Brachionidae, Cyclopoidae, and Sididae or the Genera *Bosmina*, *Brachionus*, *Diaphanosoma*, *Keratella*, and *Platyias* for August

1996. The dominant zooplankton families and genera change from month to month according to the life cycles of the organisms themselves. At these lower taxonomic resolutions, greater than 10 samples are often required to detect even a 50% decrease in the observable mean abundance and greater than 200 samples are needed to detect a 10% decrease. Although a 50% percent decrease in mean abundance may be statistically significant, it has not yet been established as to what percent change is ecologically significant. In support of this, Evans and Sell (1983) caution against interpreting the ecological significance of differences in population means less than 150% for very limited data sets (small database).

Three strategies emerge for increasing the power of analysis when considering zooplankton sampling designs. 1) The greatest power can be achieved for studies that focus at the macro scale of zooplankton abundance for which fewer samples are required with identification to the Kingdom, Phylum, Class or Order levels of resolution. 2) The same level of power can be achieved with few samples for studies that focus at the micro scale of zooplankton abundance with primary interest in the few dominant Genera present. Costs associated with these types of studies are much reduced because the zooplankton are identified at a higher taxonomic classification. 3) If the primary focus of the study is on specific non-dominant or rare species and genera, a very large number of replicate samples will be required to detect even a 50% reduction in the mean density. This will significantly increase the cost of

the study because of the taxonomic expertise required to identify organisms to species and the increased number of replicate samples required.

The 1996-1997 Lake Texoma water quality monitoring project was labor intensive with regard to zooplankton collection and identification. Based on the findings above, collection of 3 replicate zooplankton samples from each station in future studies are sufficient for water quality monitoring purposes. Zooplankton should be identified to species once each season to maintain a species list and to genera for the remainder of the sampling dates. To achieve the greatest power, zooplankton should be analyzed at the Kingdom, Phylum and Order levels to monitor seasonal and annual trends. Large departures from expected seasonal densities would warrant a more intensive sampling regime.

Table 1 Comparison of average power among 3, 5, 7 and 10 replicate samples at six taxonomic levels for the months of August 1996, January 1997 and May 1997. Data are based on a log linear model with beta = 0.1 and alpha = 0.1 using the intensive stations (3, 9, 17, 22, and 24).

		August-96		January-97		May-97	
		Mean	Average	Mean	Average	Mean	Average
Metric	Reps	Org/L	% diff	Org/L	% diff	Org/L	% diff
Kingdom	3	230.69	27.50	286.15	13.30	323.66	23.70
	5	219.14	21.60	256.57	16.40	356.11	16.00
	7	209.51	17.00	256.94	12.30	350.28	12.40
	10	207.13	13.70	252.42	9.50	355.84	10.00
Phylum	3	115.34	29.30	143.08	16.00	167.62	31.95
	5	109.57	24.25	128.28	19.40	181.75	21.75
	7	104.75	18.90	128.47	14.95	180.59	17.60
	10	103.57	16.05	126.21	11.75	179.43	15.90
Class	3	115.34	29.30	143.08	16.00	167.62	31.95
	5	109.57	24.25	128.28	19.40	181.75	21.75
	7	104.75	18.90	128.47	14.95	180.59	17.60
	10	103.57	16.05	126.21	11.75	179.43	15.90
Order	3	76.67	29.80	94.75	20.47	98.97	34.30
	5	72.86	25.93	84.89	19.73	104.75	23.10
	7	69.69	21.00	84.86	15.63	105.52	19.08
	10	68.93	18.03	83.34	12.70	103.10	17.18
Family	3	29.94	50.46	30.20	34.08	35.99	49.80
	5	25.19	44.63	24.85	32.32	36.26	36.93
	7	20.01	44.03	27.10	23.46	31.37	40.68
	10	21.42	33.26	26.72	19.47	33.60	31.86
Genus	3	18.81	56.64	21.71	40.12	27.39	52.05
	5	15.52	50.07	18.37	35.20	23.53	51.03
	7	13.98	45.26	19.46	27.47	22.34	49.24
	10	19.31	36.85	19.13	22.91	23.65	37.94

Table 2 Comparison of sample sizes required to detect a specific percent reduction in mean (org/L) at different taxonomic classifications. Data (August 1996 intensive stations using ten replicates) are based on a log linear model with beta = 0.1 and alpha = 0.1. NA indicates greater than 200 samples are required.

Metric	% Reduction of Mean:	50%	40%	30%	20%	10%	Mean Count
Kingdom	Animalia	1	1	1	1	4	207.13
Phylum	Arthropoda	1	1	1	2	7	95.48
	Rotifera	1	1	1	2	6	111.65
Order	Cladocera	1	2	3	6	24	26.85
	Calanoida	2	3	5	12	48	13.43
	Cyclopoida	2	2	4	8	33	19.30
	nauplius	1	1	2	4	16	40.71
	Ploima	1	1	1	2	6	111.41
Family	Bosminidae	2	3	5	11	46	14.05
	Brachionidae	1	1	1	2	6	110.04
	Cyclopoidae	2	2	4	9	35	18.18
	Daphnidae	7	11	19	44	183	3.46
	Diaptomidae	4	7	12	26	110	5.73
	Ergasilidae	18	29	59	134	NA	1.13
	Sididae	2	4	6	14	54	11.95
	Synchaetidae	18	27	56	128	NA	1.21
Genus	*Acanthocyclops*	18	33	59	136	NA	1.13
	Bosmina	2	3	5	11	46	14.05
	Brachionus	1	2	3	5	21	30.54
	Ceriodaphnia	15	25	46	105	NA	1.43
	Daphnia	8	13	22	52	NA	3.00
	Diaphanosoma	2	4	6	14	54	11.95
	Diaptomus	4	7	12	26	110	5.73
	Ergasilus	18	29	59	134	NA	1.13
	Keratella	2	3	4	9	38	16.80
	Mesocyclops	4	7	14	30	126	5.05
	Platyias	1	1	1	3	11	62.69
	Polyarthra	18	27	56	128	NA	1.21

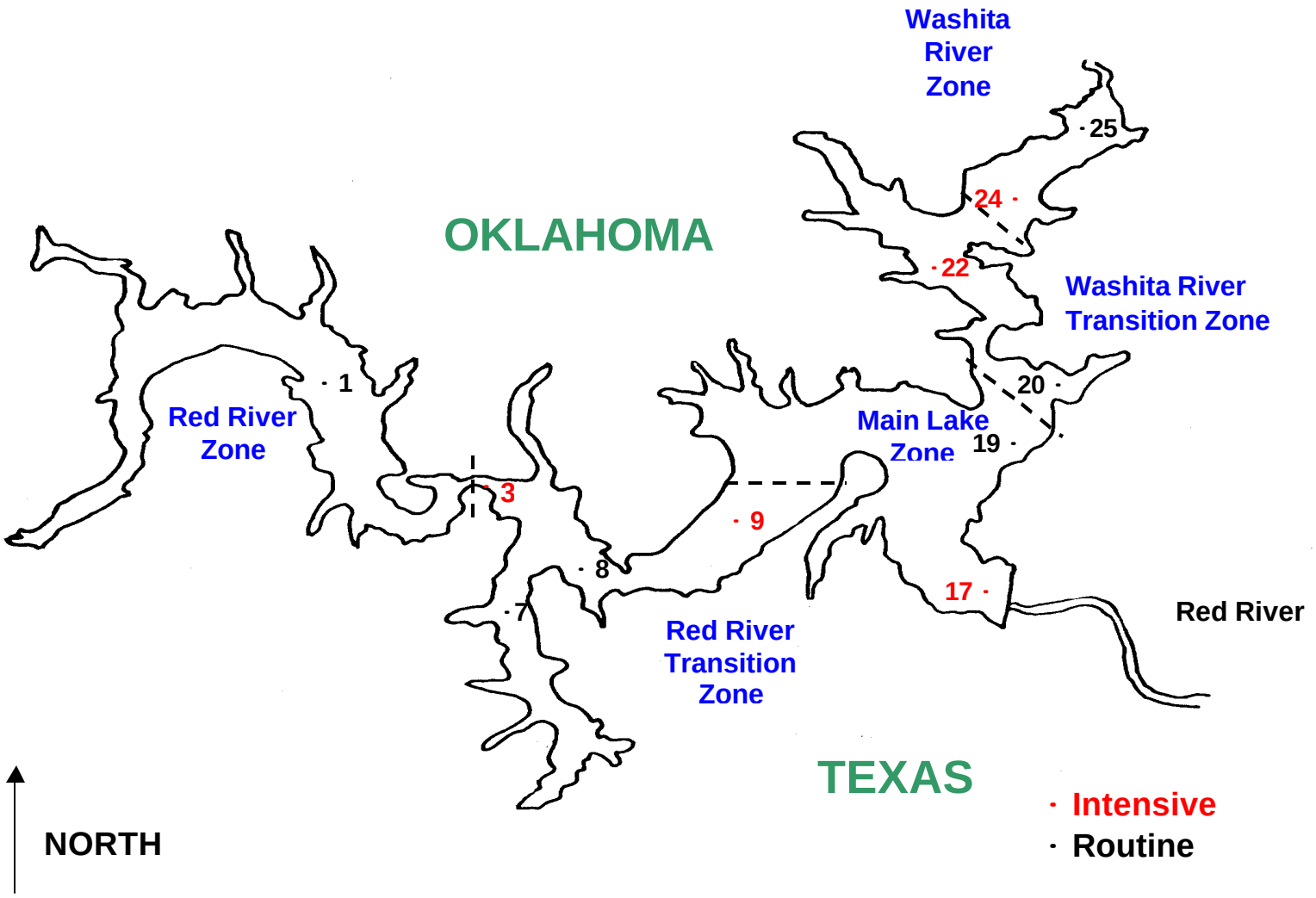

Figure 1 Map of Lake Texoma showing routine and intensive fixed station locations with each zone.

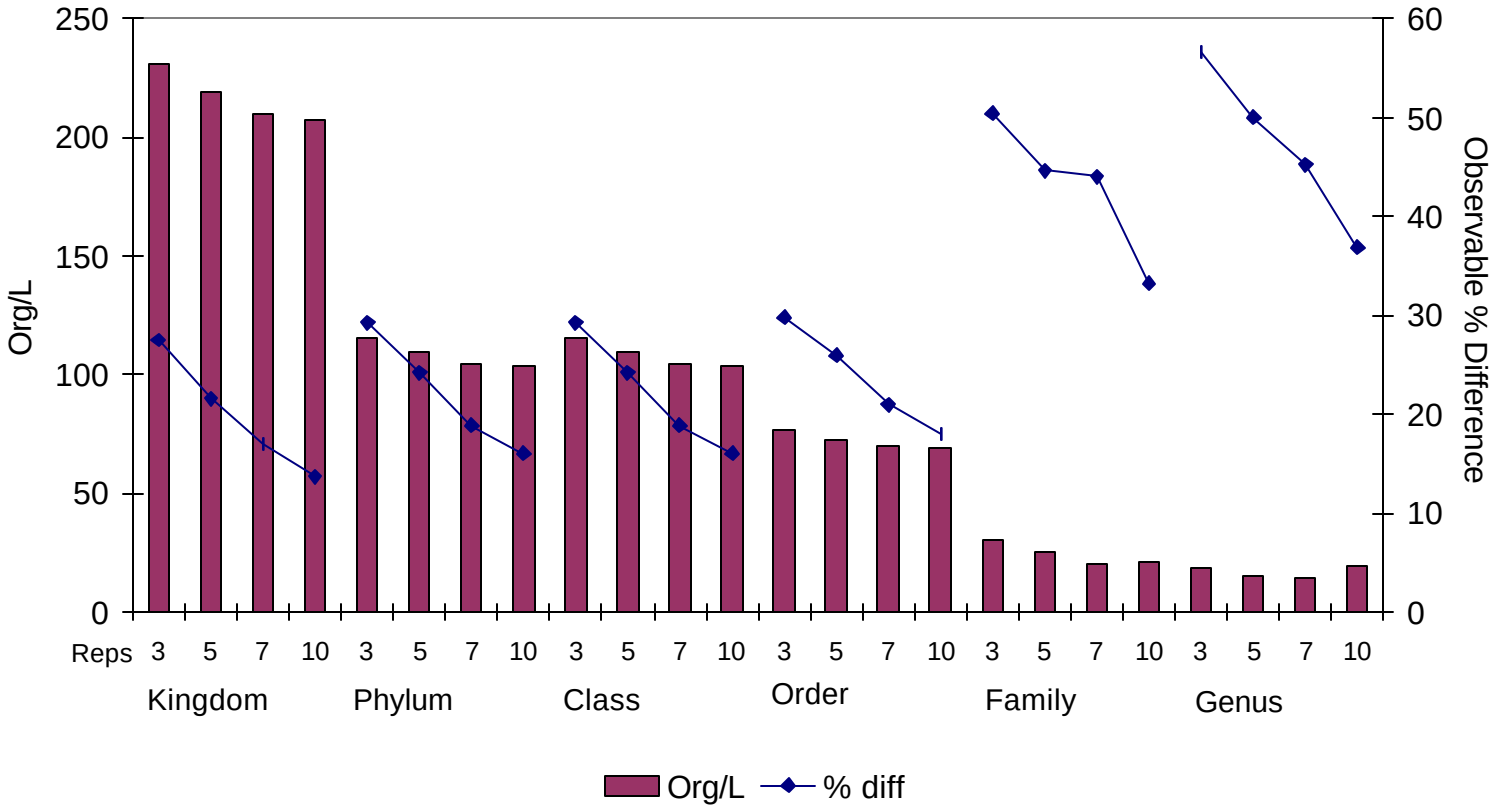

Figure 2 Comparison of results for the August 1996 power analysis using four groups of replicate samples and six taxonomic resolutions.

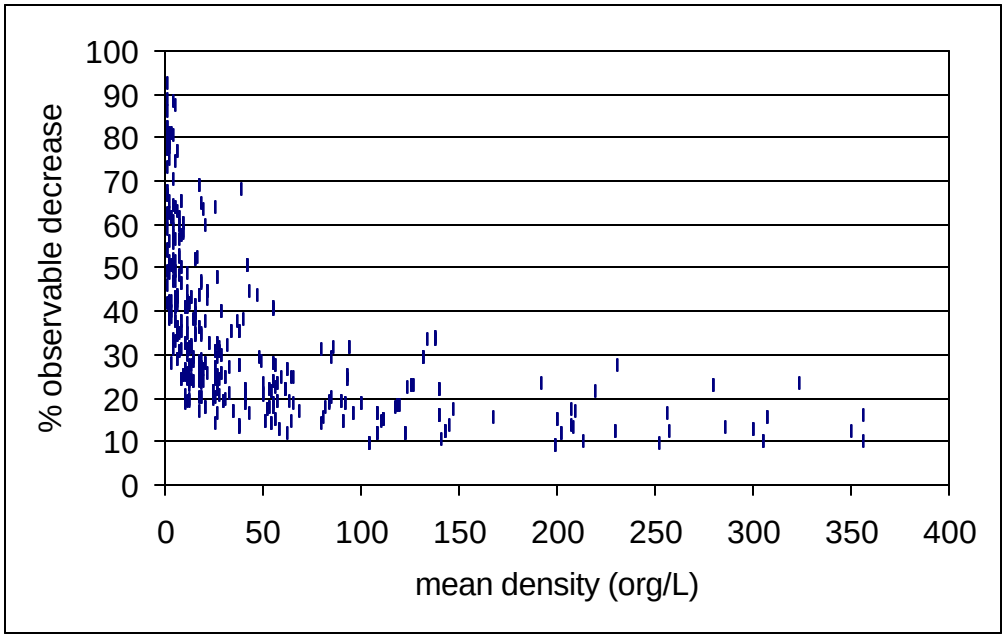

Figure 3 Relationship between zooplankton density and percent observable decrease using combined data from August 1996, January 1997 and May 1997 analyses (n=468).

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ASSESSING ZOOPLANKTON TAXONOMIC SUFFICIENCY FOR MONITORING WATER QUALITY IN LAKE TEXOMA

Introduction

Common practice is to identify organisms to either the species level or lowest possible taxon. This practice is especially costly in terms of time and expertise needed to accurately make such identifications. Accuracy of identification increases with each higher level of classification, which of course improves the quality of information gained. If the same inferences can be drawn from identifications made to higher taxonomic levels, then the species level information is considered redundant (Ferraro and Cole 1992). The concept of taxonomic sufficiency grew from the need to reduce redundant information while simultaneously improving the quality of information gained. Taxonomic sufficiency as described by Ellis (1985) is the pragmatic concept of identifying organisms only to the taxonomic level necessary and sufficient to meet a study's objective(s).

Taxonomic sufficiency has been shown to be useful for pollution assessment and water quality monitoring studies using macrobenthic organisms. Ferraro and Cole (1995) recommend family level identifications for macrobenthic organisms collected along a pollution gradient in the Southern California Bight using an optimal sampling protocol (5 replicate, 0.02 m^2 x 5 cm deep, 1.0 mm mesh samples per station) because familial analyses were found to be sufficient

for accessing pollution impacts on macrobenthic taxa richness, dominance, and diversity. Bowman and Bailey (1997) reanalyzed 10 freshwater macrobenthic data sets at different taxonomic resolutions. For these data sets, genus level identification did not result in different descriptions of community patterns from that of higher levels of taxonomic identification. Ammann and others (1997) investigated taxonomic sufficiency by reanalyzing data from a series of marine microcosm experiments investigating the relationship between laboratory and ambient toxicity in macrobenthics at Santa Rosa Sound, Florida. In 85.7% of the experiments, phylum level identifications were as sensitive as or more sensitive than any other metric analyzed, in 3.6% of the experiments, class level identifications were as sensitive as or more sensitive than any other metric, and in 11.7 of the experiments, order level identifications was as sensitive as or more sensitive than any other metric.

The application of taxonomic sufficiency to water quality monitoring studies using zooplankton abundance has not been addressed. In such studies, zooplankton are commonly identified to either genus or species because this information is required when using diversity indices (Resh and Unzicker 1975) or compiling species lists. Trends in abundance and community structure are typically analyzed by grouping the species data into general classifications such as crustaceans and rotifers, or cladocera, copepods and rotifers. Sometimes, juvenile stages are grouped separately in the copepods. Analyzing species or generic data at each level of taxonomic classification may help to determine the taxonomic sufficiency required for reservoir water quality monitoring. Once

taxonomic sufficiency is established to meet the programs objectives, it can be applied to future monitoring programs.

An intensive 14 (August 1996 - September 1997) water quality monitoring program was conducted on Lake Texoma to establish a baseline for physical-chemical and biological information. Species level or lowest possible taxon identifications were made on zooplankton collections. Data were analyzed at each taxonomic level of classification on a per sampling trip basis and whole study (combined data from all sampling trips) basis to determine taxonomic sufficiency for this study. Analyses performed on lower levels of classification were compared to the successive higher levels of classification to determine the highest level of classification for which the analysis did not change. Special attention is focused on information loss from species level identifications to genus level identifications.

Methods

Lake Texoma is a 36,000 hectare multipurpose impoundment with a drainage basin of approximately 103,000 km^2, most of which is pasture and cropland. It occupies portions of both south central Oklahoma and north central Texas. Major rivers flowing into Lake Texoma are the Red River from the west, which forms the southern border between Oklahoma and Texas and the Washita River from the north. At normal pool elevation (617.0 ft), maximum depth is 34 m and mean depth is approximately 9 m. (Atkinson and others 1999).

One thousand seventy-seven zooplankton samples were collected from August 1996 through September 1997 from 16 stations divided among 5 zones (Figure 1). Each zone contains 3 stations except the Red River Transition zone which contains an additional station to monitor the influence of loadings on this zone by the Big Mineral Arm. Of the 11 fixed stations, 5 were designated as intensive stations from which 10 replicate zooplankton samples were collected. Three replicate samples were collected at each of the remaining 6 fixed stations and 5 random stations. Samples were collected monthly except as follows: 1) samples were not collected for the months of October, December and February because the historical data shows little change in the physical-chemical parameters during the winter months, and 2) samples were collected twice monthly for May and June when physical-chemical and biological changes are most dynamic.

Zooplankton samples were collected by a ten-meter vertical tow using a No. 20 nylon plankton net fitted with a Wisconsin bucket (80 micron mesh) for concentrating samples in the field. For stations less than 11 meters in depth, vertical tows were taken from one meter off the bottom. Station depth was determined using sonar technology. Contents of the Wisconsin bucket were thoroughly washed with distilled water into a prelabeled 125 ml polyethylene sample collection jar and preserved with acidified Lugols solution (Wetzel and Likens 1979).

Zooplankton were subsequently enumerated by placing a 1 ml aliquot from each sample onto a Sedgwick-Rafter counting chamber. A Hensen-

Stemple pipette was used to obtain the 1 ml aliquot. Zooplankton sample volumes were adjusted individually such that a minimum of 170 to 200 organisms were counted in the 1 ml aliquot. When zooplankton abundance was extremely low, it was necessary to count several 1 ml aliquots to obtain the minimum count of 200 organisms per sample. Adjusted sample volumes were recorded for calculation of zooplankton density. The entire content of the 1 ml aliquot was counted using a compound light microscope at 125x magnification. The entire sample was counted for the cladoceran, *Leptodora kinditi*, because of the sampling bias associated with its large size.

Zooplankton were enumerated and identified to the lowest possible taxon following Edmondson (1959), Stemberger (1979) and Pennak (1989). Counts were converted to organisms per liter of lake water.

Statistical Analyses

An *a priori* decision was made to delineate the study area into zones based upon findings from a review of the historical water quality data (Atkinson and others 1996). Analyses were performed on all samples collected within a zone consisting of 19 samples for the Red River Transition zone and 16 samples for the remaining 4 zones. Statistical analyses were performed for all taxonomic levels of classification using Splus Version 4.0 software. The hypothesis tested states that for each sampling trip, there is no significant difference in the mean number of organisms per liter between zones for each taxonomic level of classification. To test this hypothesis, count data from each sampling date for

the replicate samples within a zone were assessed for uniformity in dispersion using Levene's test for homogeneity of dispersion (α=0.10). If the Levene's test showed there was no significant difference in dispersion ($p \geq 0.10$), then a one way analysis of variance (Poisson model) was performed to determine if there was a statistically significant difference in zooplankton abundance between zones. If the ANOVA showed there was a statistically significant difference in mean zooplankton abundance between zones ($p < 0.10$), a Tukey's multiple comparison test was used to separate the means. If the Levene's test showed the samples were not uniformly dispersed ($p > 0.10$), then a Kruskal-Wallis rank sum test was used followed by a Tukey's multiple comparison test to separate the medians if statistical significance was gained. Figure 2 is a decision tree summarizing the process described above.

For each sampling date and organism identified, statistical outcomes for each taxonomic level of classification were compared to determine at which level of classification the outcome did not change from that of lower levels. For example, the outcome at the species level (lowest taxonomic level) for *Brachionus angularis* was compared to that at the genus level (higher taxonomic level), *Brachionus*. If the statistical outcomes were different, it would be necessary to make identification to the species level (lower taxonomic level) to retain the most information. However, if the statistical outcomes were the same, then the outcomes for the genus Brachionus and family Brachionidae levels of classification would be compared. If the statistical outcomes were different, then no further comparisons would be made and genus would be the highest level of

classification for which the analysis remained the same. Therefore, identification could be stopped at the genus level without losing any information. Two situations were compared: 1) zooplankton identified to species (Table 3) and zooplankton identified to only genus (Table 4).

Results

The zooplankton assemblage (August 1996 - September 1997) was comprised of 71 species representing 39 genera from the Rotifera, Cladocera, Cyclopoida, Calanoida and Harpacticoida. Tables 1 and 2 lists the taxonomic classification for the most common species present in Lake Texoma during this study. "Common species" is arbitrarily defined as those zooplankton present in ≥ 10% of the samples (n=1076). Those species omitted are not necessarily unimportant, but often were littorial species that may have drifted on the currents into the limnetic regions of the lake. Of the Crustacea species, 55.0% of the Cladocera, 87.5% of the Cyclopoid and 80.0% of the Calanoid species were considered common. Forty-three percent of the Rotifera species were considered common. It was not necessary to identify each organism to the species level because a single family or genus (bold names in Tables 1 and 2) represented some organisms. For example, of the 45 species listed in Tables 1 and 2, ten were represented by a single family and could have been identified to the family level of classification without losing any information. Likewise, for 6 species, identifications could have been made to the genus level only.

Tables 3 and 4 summarize for each of the common species and genera (respectively), the lowest level of classification for which each species and or genera was present in Lake Texoma during this study, number of sampling trips for which it was present, number of zones in which the organism was present; and the highest level of taxonomic classification for which the statistical analysis did not change. For example, the lowest level of classification present for *Bosmina longirostris* would be the family Bosminidae because this family is represented by only one genus and species in Lake Texoma during this study. Identification of this organism to genus or species results in redundant information. Species marked with a double asterisk (**) in Table 3 indicate those organisms for which the statistical analysis will be the same as that of genus because only a single species was present. The rotifer genera *Asplanchna, Collotheca, Ascomorpha* and *Synchaeta* are not included in the Table 3 because they were identified to genus only.

Identification to Species

For the 36 species listed in Table 3, eight species could have been identified to family and 3 species could have been identified to genus without losing any information for any single sampling trip. In other words, identifications could have been made to a higher level of classification in approximately 30% of the species without altering the outcome of the analysis. For example, the cladoceran *Ceriodaphnia quandrangula* was present during 11 of the 13 sampling dates. On 7 of the 11 sampling dates, the analysis could have been performed at the genus level obtaining the same information as if it had been

performed at the species level. For the species *Ceriodaphnia quadrangula*, *Mesocyclops edax*, *Notholca acuminata*, *Playtias patulus*, *and Polyarthra dolichoptera*, the analysis would have been the same at the genus level on more than 50% of the sampling dates. On all 6 sampling dates for which *Leptodora kinditii* was present, the analysis could have been performed at the family level obtaining the same information as if it had been run at the species level. For 8 species, whose lowest level of classification was family, the analysis could have been performed at the order level obtaining the same information as if it had been run at the species level. For the remaining 70% of the species, the analysis should be run at the species level of classification to retain all the information.

Identification to Genus Only

Table 4 represents the same kind of information as Table 3 except that count data were analyzed as if the zooplankton had been identified only to the genus level of classification. For the 25 genera listed in Table 3, approximately 40% or 10 genera could have been identified and analyzed at the family level without losing any information. For less than 50% of the sampling dates, approximately 43% of the genera present at the family level in Lake Texoma (mostly rotifers), could have been identified and analyzed at the order level and still obtained the same information as if the analysis had been run at the genus level. For the remaining 60% of the genera, the analysis should be run at the genus level of classification to retain all the information.

Comparison with Whole Study Analysis

Tables 5 (species level) and 6 (genus level) summarize information in the last major column of Tables 3 and 4, respectively, and compare the results to the results obtained from a whole study analysis (combining the count data for all thirteen sampling trips). The classification reported in the month column of Tables 5 and 6 represents the classification with the highest number reported in Tables 3 and 4, respectively. For example in Table 5, *Ceriodaphnia quadrangula* was present in 11 of the 13 sampling trips. Seven of the 11 analyses could have been conducted at the genus level of classification without losing any information while the 4 remaining analysis had to be taken to the species level of classification. Therefore, since the genus level of analysis was appropriate for the majority of the sampling trips, genus is shown in the monthly column in Table 5 for this species. Comparing the results of the monthly analysis to that of the whole lake analysis at the species level, 6 out of 36 monthly analyses differed from that for the whole study analysis. *Ceriodaphnia quandrangula* and *Mesocyclops edax* and *Diaptomus connexus* would need to be identified to species level, rather than a higher level of classification, when combining the data into a single whole lake study. Analyzing C*eriodaphnia reticulata*, *Brachionus calyciflorus* and *Polyarthra dolichoptera* at the genus level of classification for the whole lake study, rather than species, does not make sense because there are other species present in each of these genera. With one exception, there is no difference between the results of the monthly and whole lake analyses at the genus level.

Discussion

Routine monitoring of zooplankton abundance can be quite costly in terms of time and expertise needed to accurately make such identifications. One way to reduce these costs would be to identify zooplankton to a higher level of classification than species. To examine what effect this might have for different levels of classification, comprehensive zooplankton data from a fourteen month study (August 1996 - September 1997) on Lake Texoma was analyzed at each taxonomic level of classification, both on a monthly basis and whole lake basis (combined data from all dates and stations) and the outcomes compared. For most analyses, the outcomes differ from one level of classification to the next. This difference occurs because at each lower level of classification the abundance becomes smaller and smaller. For example, the largest abundance occurs at the Kingdom level. The Kingdom abundance, in the case of Lake Texoma is separated into two phyla Animalia and Rotifera. At the next lowest level of classification, the abundance in each phyla is separated into classes; and so on down to the lowest level to which an organism is identified. Therefore, the smallest abundance value for an organism occurs at the lowest level to which it was identified. With this in mind, information is lost for each higher level of classification for which an organism is identified or for which an analysis is performed. Analyzing data at levels higher than species can result in an increase in sample size because not all samples will contain the same species. It is more likely that all samples could contain the same genera or families because these higher levels of classification are often represented by more than one species.

Therefore, analyzing data at the higher levels of classification may increase the power or sensitivity of the analysis to detect differences in mean zooplankton abundances that would not otherwise be detected at lower levels of classification. The end result is that the null hypothesis may be rejected more often at the lower levels of classification than at the higher levels.

Some species of zooplankton in Lake Texoma could have been identified to a higher level of classification without affecting the outcome of analyses performed at lower levels of classification for these species. For example, of the 38 species identified from Lake Texoma, 10 of the species or 26% were represented by a single family negating the necessity of identifying those beyond the family level of classification. These families were primarily associated with the cladocera (3) and rotifers (5). Likewise, 6 of the species or 16% could have been identified to the genus level of classification without affecting the outcome of species level analyses. These genera were primarily associated with cyclopoids (3) and rotifers (3). Such information can only be gained from an initial baseline study with zooplankton identifications to species level, preferably over an annual cycle. Knowing this information can reduce time spent identifying zooplankton to levels of classification that provide redundant information.

The highest level of classification to which an organism could be analyzed without producing a different outcome at the species level of classification analyses differed from month to month (Table 3). With a few exceptions, genus level analyses differed from species level analyses indicating that species level identifications and analyses were necessary to retain the most information.

Comparing the monthly analyses to that of the whole lake analyses produced similar results.

The highest level of classification to which an organism could be analyzed without producing a different outcome at the genus level of classification analyses also differed from month to month (Table 4). With a few exceptions, family level analyses differed from genus level analyses indicating that genus level identifications and analyses were necessary to retain the most information. Comparing the monthly analyses to that of the whole lake analyses produced almost identical results.

The purpose or objective of a study should be of primary concern when deciding the appropriate taxonomic level in which to identify zooplankton. For water quality monitoring studies, like the current study of Lake Texoma, it may not be necessary to identify zooplankton to species after the initial study because zooplankton community composition in a reservoir remains fairly constant for many decades (Gannon and Stemberger 1978). From a fisheries or lake productivity standpoint, interest is often times focused on the crustacean zooplankton, therefore, identification to family may be all that is needed. Water quality monitoring studies, at a minimum, include physical-chemical and biological data. From these two types of data, water quality is assessed for independent points in time and location throughout a water body for the duration of the study, oftentimes less than a year. The data collected serve as a baseline to which subsequent studies can be compared. Initially, zooplankton should be identified to species to compile a comprehensive species list, identify seasonal

cycles for the individual species, and examine general trends in zooplankton abundance and percent composition. Once the baseline data are collected and examined, zooplankton could be then identified to family or genus. Species identification could be limited to a small subset of samples from each sampling trip or quarterly collections. Consistent major changes in zooplankton composition and abundance at the family or genus level might be an indication of changing water quality. Such a design would reduce costs in subsequent programs and still provide enough information to detect possible changes in water quality.

Table 1 Taxonomic listing of common crustacean zooplankton species found in Lake Texoma from August 1996 - September 1997. Bold names indicate lowest taxonomic level present.

Order	Suborder	Family	Genus	Species
Phylum Arthropoda, Class Crustaceae				
Cladocera		**Bosminidae**	*Bosmina*	*longirostris*
		Diaphnidae	*Ceriodaphnia*	***quadrangula***
			"	***reticulata***
			Daphnia	***ambigua***
			"	***galaeta mendotae***
			"	***lumholtzi***
			"	***parvula***
			"	***pulex***
		Leptodoridae	*Leptodora*	*kindti*
		Sididae	*Diaphanosoma*	*bergei*
Copepoda	Calanoida	Diaptomidae	*Diaptomus*	***connexus***
			"	***saltillinis***
		Temoridae	*Eurytemora*	*affinis*
		calanoid copepodid		
	Cyclopoida	Cyclopoidae	***Acanthocyclops***	*vernalis*
			Cyclops	*bicuspidatus*
			Ectocyclops	*phaleratus*
			Mesocyclops	***edax***
			"	***inversus***
		cyclopoid copepodid		
		Ergasilidae	*Ergasilus*	*versicolor*
		nauplius		

Table 2 Taxonomic listing of common rotifer zooplankton species found in Lake Texoma from August 1996 - September 1997. Bold names indicate lowest taxonomic level present.

Order	Suborder	Family	Genus	Species
Phylum Rotifera, Class Monogonta				
Floscullariacea		**Conochilidae**	*Conochiloides*	*dossarius*
		Filiniidae	*Filinia*	*longiseta*
		Hexarthridae	*Hexarthra*	*mira*
Ploima		**Asplanchnidae**	*Asplanchna*	*sp.*
		Brachionidae	*Brachionus*	***angularis***
			"	***budapestinensis***
			"	***calyciflorus***
			"	***caudatus***
			"	***urceolaris***
			"	***varibilis***
			Keratella	***cochlearis***
			"	***quadrata f. testudo***
			Notholca	*acuminata*
			Platyias	***patulus***
		Collothecadae	*Collotheca*	*sp.*
		Gastropodidae	***Ascomorpha***	*sp.*
		Synchaetidae	*Polyarthra*	***dolichoptera***
			"	***euryptera***
			Synchaeta	*sp.*
		Trichocercidae	*Trichocera*	***lata***
			"	***multicrinis***
			"	***similis***

Table 3 Species level zooplankton identifications information including the lowest taxonomic level present in Lake Texoma during this study, classification of occurrence during the thirteen sampling dates and highest level of classification for which the statistical analysis does not differ from that of lower levels of classification.

Species	Lowest Taxonomic Level Present	No. Sampling Dates Present	Present in one zone only	Not Present	Highest Level of Classification Which Does Not Yield Difference in Statistical Analysis: Order	Suborder	Family	Genus	Species
CLADOCERA									
Ceriodaphnia quadrangula	S	11	1	1		NA		7	4
Ceriodaphnia reticulata	S	10	2	1		NA		1	9
Daphnia galaeta mendotae	S	10	1	2		NA		1	9
Daphnia lumholtzi	S	8	3	2		NA			8
Daphnia parvula	S	6	4	3		NA	1	1	4
Daphnia pulex	S	10	3			NA			10
Bosmina longirostris **	F	13			3	NA	10		
Leptadora kinditii **	F	6		7		NA	6		
Diaphanosoma bergei **	F	10	2	1		NA	10		
COPEPODS									
Calanoids									
Diaptomus connexus	S	12	1				8		4
Diaptomus saltillinis	S	5	4	4					5
Eurytemora affinis **	F	12		1		1	11		
Cyclopoids									
Mesocyclops edax	S	13						8	5
Mesocyclops inversus	S	11	1	1				3	8
Acanthocyclops vernalis **	G	11	1	1				11	
Cyclops bicuspidatus **	G	9	2	2				9	
Ectocyclops phaleratus **	G	12	1					12	
Ergasilus versicolor **	F	9	2	2			9		
ROTIFERS									
Brachionus. angularis	S	11	1	1	1	NA		3	7
Brachionus budapestinensis	S	6	3	5		NA			5

Table 3 Continued

Species	Lowest Taxonomic Level Present	No. Sampling Dates Present	Present in one zone only	Not Present	Highest Level of Classification Which Does Not Yield Difference in Statistical Analysis				
					Order	Suborder	Family	Genus	Species
Brachionus calyciflorus	S	12	1			NA			12
Brachionus caudatus	S	8	2	3		NA		1	7
Brachionus urceolaris	S	8	4	1		NA			8
Brachionus varibilis	S	6		7		NA			6
Keratella cochlearis	S	13				NA		1	12
Keratella quadrata f. testudo	S	13				NA	1	2	10
Notholca acuminata	S	6	4	3		NA		4	2
Playtias patulus	S	10	2	1		NA		9	1
Polyarthra dolichoptera	S	13				NA	3	8	2
Polyarthra euryptera	S	8	3	2		NA			8
Trichocera lata	S	3	2	8		NA	1		2
Trichocera multicrinis	S	8	3	2		NA	2		6
Trichocera similis	S	3		10		NA			3
Conochilius dossarius	F	9	3	1	2	NA	7		
Filinia logisetta	F	8	3	2	2	NA	6		
Hexarthra mira	F	11		2	4	NA	7		

** same outcome if identified to genus only

S = Species, G = Genera, F = Family

Table 4 Genus level zooplankton identifications information including the lowest taxonomic level present in Lake Texoma during this study, classification of occurrence during the thirteen sampling dates and highest level of classification forwhich the statistical analysis does not differ from that of lower levels of classification.

Genus	Lowest Taxonomic Level Present	No. Sampling Dates Present			Highest Level of Classification Which Does Not Yield Difference in Statistical Analysis			
		Present	in one zone only	Not Present	Order	Suborder	Family	Genus
CLADOCERA								
Ceriodaphnia	G	11	2			NA		11
Daphnia	G	13			2	NA	7	4
Bosmina	F	13			3	NA	10	
Leptodora	F	6		7		NA	6	
Diaphanosoma	F	10	2	1		NA	10	
COPEPODS								
Calanoids								
Diaptomus	F	13				3	10	
Eurytemora	F	12		1		2	10	
Cyclopoids								
Acanthocyclops	G	11	1	1				11
Cyclops	G	9	2	2				9
Mesocyclops	G	13					1	12
Ectocyclops	G	12	1					12
Ergasilus	F	9	2	2			9	
Developmental Stage								
cyclopoid copodid	group	13				4	9	
calanoid copodid	group	13				1	12	
nauplii	group	13			4		9	
ROTIFERS								
Ascomorpha	G	7	5	1		NA	6	1
Asplanchna	F	13			2	NA	11	
Brachionus	G	13			2	NA	4	7
Keratella	G	13				NA	2	11

Table 4 Continued

Genus	Lowest Taxonomic Level Present	No. Sampling Dates Present	Present in one zone only	Not Present	Highest Level of Classification Which Does Not Yield Difference in Statistical Analysis			
					Order	Suborder	Family	Genus
Notholca	G	6	4	3		NA		4
Platyias	G	10	2	1		NA		10
Polyarthra	G	13				NA	3	10
Synchaeta	G	12		1		NA	2	10
Trichocera	G	13				NA	9	4
Collotheca	F	7	1	4		NA	7	
Conochilius	F	9	3	1	2	NA	7	
Filinia	F	8	3	2	2	NA	6	
Hexarthra	F	11		2	4	NA	7	

Table 5 Comparison of species level of analysis for whole lake and single sampling trips. Whole lake analysis includes all thirteen sampling trips. The (*) shows where the analyses differ. F = family, G = genus and S = species

Species	Monthly	Whole Study		Monthly	Whole Study
CLADOCERA			COPEPODS		
Bosmina longirostris	F	F	Calanoids		
			Diaptomus connexus	F	S*
Ceriodaphnia quadrangula	G	S*			
			Diaptomus saltillinis	S	S
Ceriodaphnia reticulata	S	G*			
			Eurytemora affinis	F	F
Daphnia galaeta mendotae	S	S			
			Cyclopoids		
Daphnia lumholtzi	S	S	*Acanthocyclops vernalis*	G	G
Daphnia parvula	S	S	*Cyclops bicuspidatus*	G	G
Daphnia pulex	S	S	*Mesocyclops edax*	G	S
Leptadora kinditii	F	F	*Mesocyclops inversus*	S	S
Diaphanosoma bergei	F	F	*Ectocyclops phaleratus*	G	G
			Ergasilus versicolor	F	F
ROTIFERS			ROTIFERS		
Brachionus. angularis	S	S	*Keratella cochlearis*	S	S
Brachionus budapestinensis	S	S	*Keratella quadrata f. testudo*	S	S
Brachionus calyciflorus	S	G*	*Notholca acuminata*	G	G
Brachionus caudatus	S	S	*Plytias patulus*	G	G
Brachionus urceolaris	S	S	*Polyarthra dolichoptera*	S	G
Brachionus varibilis	S	S	*Polyarthra euryptera*	S	S*
Conochilius dossarius	F	F	*Trichocera lata*	S	S
Filinia logisetta	F	F	*Trichocera multicrinis*	S	S
Hexarthra mira	F	F	*Trichocera similis*	S	S

Table 6 Comparison of genus level of analysis for whole lake and single sampling trips. Whole lake analysis includes all thirteen sampling trips. The (*) shows where the analyses differ. F = family, G = genus

Genus	Monthly	Whole Study
CLADOCERA		
Bosmina	F	F
Ceriodaphnia	G	G
Daphnia	F	F
Leptodora	F	F
Diaphanosoma	F	F
COPEPODS		
Calanoids		
Diaptomus	F	F
Eurytemora	F	F
Cyclopoids		
Acanthocyclops	G	G
Cyclops	G	G
Mesocyclops	G	G
Ectocyclops	G	G
Ergasilus	F	F
Developmental Stage		
cyclopoid copodid	F	F
calanoid copodid	F	F
nauplii	F	F
ROTIFERS		
Ascomorpha	F	G*
Asplanchna	F	F
Brachionus	G	G
Keratella	G	G
Notholca	G	G
Platyias	G	G
Polyarthra	G	G
Synchaeta	G	G
Trichocera	F	F

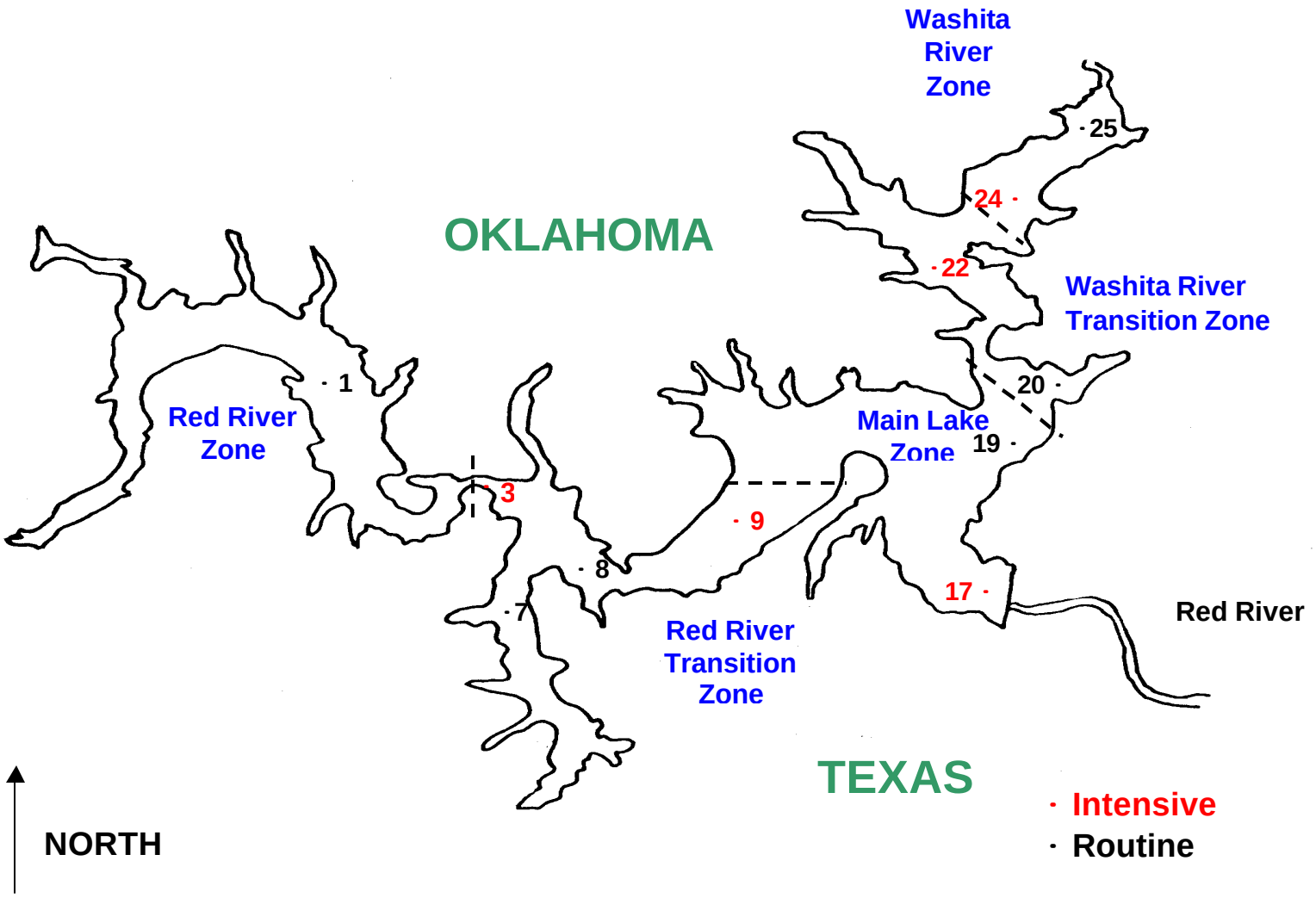

Figure 1 Map of Lake Texoma showing routine and intensive fixed station locations with each zone.

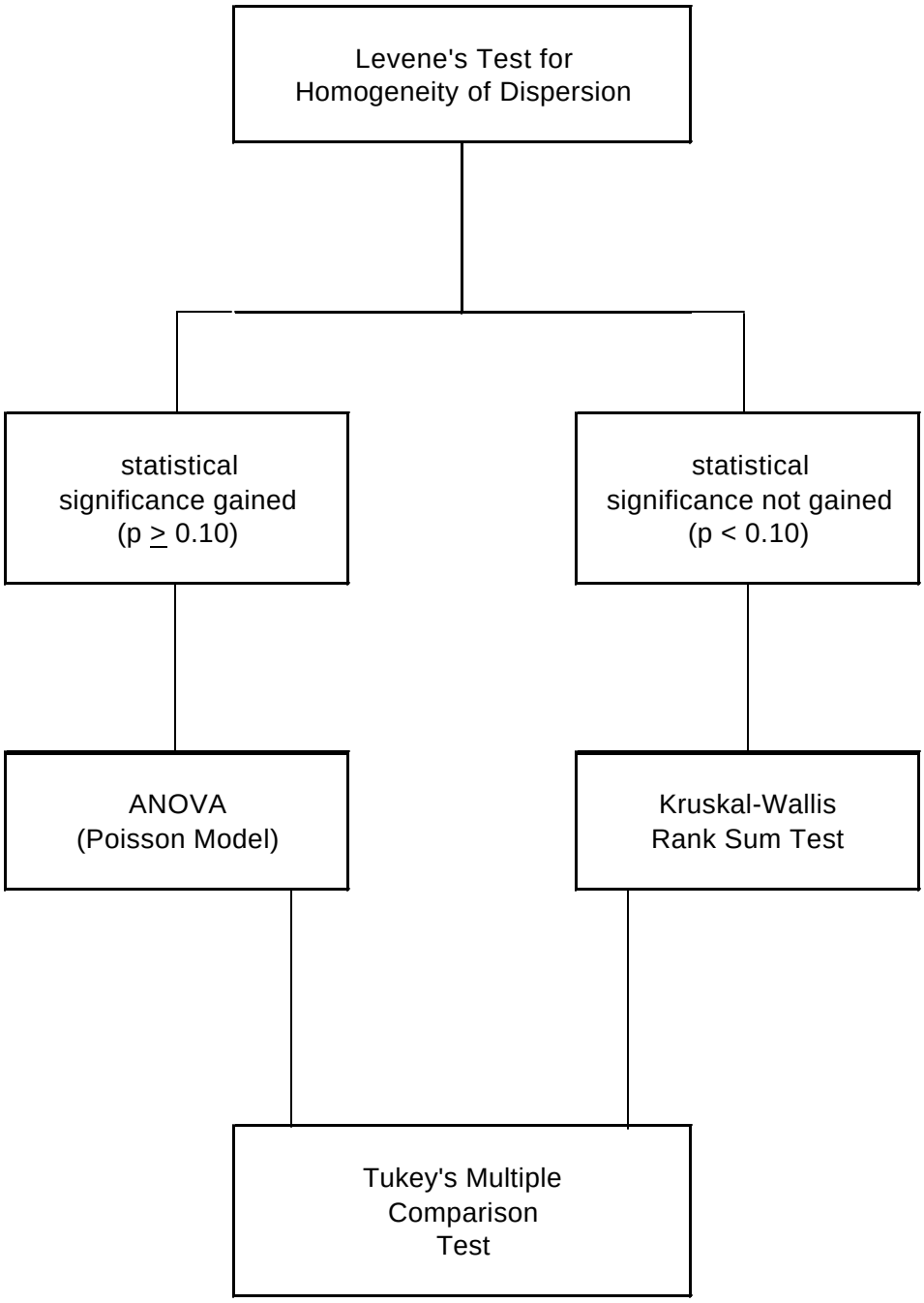

Figure 2 Decision tree showing circumstances when each type of analysis was used.

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CONCLUSIONS

Lake Texoma is a 36,000 hectare multipurpose impoundment which occupies portions of both south central Oklahoma and north central Texas. Completed in 1944, it is the twelfth largest reservoir in the U.S. Lake Texoma drains an area approximately 103,000 km^2, most of which is pasture and cropland. Major rivers flowing into Lake Texoma are the Red River from the west and the Washita River from the north. Lake Texoma, known as the "striper capital of the world", is one of the few reservoirs in the nation where striped bass reproduce naturally. It is also known as the "playground of the Southwest" ranking second overall in visitation nationwide. Amenities offered in addition to boating and fishing are camping, hiking and equestrian trails.

The two rivers impounding Lake Texoma have differing water quality and flow regimes. The Washita River is slightly more turbid and has approximately a third less flow than the Red River. The Red River is characterized by high conductivity and greater flow.

Data presented in this research come from two separate studies conducted during opposing hydrologic conditions. The 1996-97 Water Quality Monitoring Program was conducted during a relatively wet time period when lake elevation levels were consistently above the conservation pool elevation of 617 feet. The 1999 Water Quality Research Program was conducted during a very dry year when the mean lake elevation was two feet below the conservation pool.

The objectives for my research are 1) to examine the zooplankton abundance and community composition temporally and spatially within the first

ten meters of Lake Texoma, 2) examine the relationship between the physical and chemical water quality parameters and the distribution of the zooplankton community, and to examine the sensitivity of this sampling program to detect shifts in zooplankton population density and community composition.

Zooplankton community composition and structure was examined for the first ten meters of Lake Texoma from August 1996 through September 1997. Lake Texoma has a diverse zooplankton community consisting of 71 species. Seasonal patterns are typical of that found in temperate reservoirs. Peak abundances occur during the spring followed by a sharp decline in summer and a modest fall increase.

Zooplankton abundance, species richness and community composition differs between the two river arms and main lake body. Density is greatest in the Red River arm, least in the main lake body and intermediate in the Washita River arm. Increased salinity in the Red River arm does not appear to be associated with increased zooplankton density in this arm. Species richness is greatest in the two river arms and least in the main lake body due to inherent differences in the physical and chemical water quality characteristics between the headwaters and the dam. Sixty-nine taxa make up the zooplankton community in the Red River arm, 64 taxa in the Washita River arm and 50 taxa in the main lake body. Species composition is similar between the Red River arm and main lake body and different in the Washita River arm. Copepods and rotifers account for approximately 70% of the zooplankton in the Red River arm and main lake body and 90% in the Washita River arm. Overall, the Washita river arm is more turbid

than the Red River arm and has less flow which may account for some of these differences.

Spatial and temporal variation in zooplankton genera and the water quality parameters were examined by stations and zones from August 1996 through September 1997. Spatial variation was separated into a fixed station/zone component and an ephemeral spatial component. Temporal variation generally exceeded spatial variation for many of the zooplankton genera and physical and chemical parameters for both station and zone analyses. Several zooplankton genera (one cladoceran and several copepod and rotifer genera) and water quality parameters (sodium, chloride, conductivity, Secchi depth, total suspended solids and turbidity) exhibited strong fixed spatial variation as would be expected for a river-run system such as Lake Texoma. These results support the presence of longitudinal gradients in water quality in Lake Texoma that in turn influence zooplankton distributions in the reservoir.

Three separate models rather than a single whole lake model, best describe the influence of abiotic factors on zooplankton species composition in Lake Texoma. Abiotic factors examined include season (spring and summer) and 21 physical and chemical variables. Although the physical and chemical factors account for a good proportion of the variance in these models, seasonal effects appear to have a much stronger influence on the zooplankton community, especially in the two river arms where the water quality characteristics are so dynamic. Physical and chemical factors appear to have more of an influence on

the zooplankton community in the deeper, less turbid main lake body where the water quality characteristics are more stable through time.

The occurrence of abnormal *Keratella cochlearis* increased significantly in 1999 from that observed in the 1997. Abnormal individuals were observed in May and June from two stations in 1997 compared to 7 stations in March and May in 1999. Deformed individuals were primarily observed at stations with greater salinity, conductivity, and turbidity measures as compared to the other stations. During both studies, deformed individuals appeared only during the spring months, suggesting the phenomenon is seasonal. No causal relationships can be drawn from the data.

The sensitivity of the sampling program to detect shifts in zooplankton population density and community composition was assessed for different numbers of replicates and levels of classification. This information is important when designing a sampling program because a balance must be obtained between number of samples collected, level of species identification, the power of the analysis, and cost. Oftentimes, cost dictate the number of samples collected and to what level species will be identified. On average, a 30% decrease in the observed mean can be detected with 3 replicate samples analyzed for the classifications Kingdom through Order. This increases to 60% if the data are analyzed at the Family or Genus levels, greatly reducing the power of the analysis. Increasing the number of samples to 10, decreases the percent observable decrease in the man abundance from 30% to 10% for analyses conducted at the higher levels of classification and from 60% to 30% for analyses

at the Family and Genus levels. Therefore, 3 to 10 replicate samples may be sufficient to monitor general trends in zooplankton abundance for the higher taxonomic classifications such as Kingdom, Phylum, Class and Order; however, if being able to detect small shifts in zooplankton abundance beyond Order s desired, 10 samples may not be sufficient.

Taxonomic sufficiency is the pragmatic concept of identifying organisms only to the taxonomic level necessary and sufficient to meet a study's objective(s). If zooplankton could be identified to a higher level of classification other than genus or species, costs in terms of time and expertise needed to accurately make such identifications could be reduced significantly. Analyzing zooplankton abundance for different levels of classification allowed comparisons of outcomes between classification levels. Overall, the analyses differed between each level of classification resulting in a loss of information from one level to the next. This suggests the necessity of species identifications to retain as much information as possible. However, because zooplankton community composition remains fairly constant for many decades, I recommend for water quality monitoring purposes, making identifications to the species level initially to compile a comprehensive species list, identify seasonal cycles of individual species, and examine general trends in abundance and composition. Once this has been completed, zooplankton could then be identified to family or genus with species identifications limited to a subset of the samples from each sampling trip or quarterly collections.

There is still a lot to be learned about the zooplankton community and its distribution in Lake Texoma. Inclusion of the phytoplankton data into the current zooplankton model for the Red River arm, main lake body, and Washita River arm will give insight into the relationship between the phytoplankton and zooplankton community. Data from the second study will provide information concerning zooplankton abundance and community structure during three consecutive years allowing for intra and inter-annual comparisons. This information will be invaluable since no multiple year zooplankton studies have been conducted on Lake Texoma. Comparison and analysis of data from both studies will give insight into the affect of contrasting hydrologic conditions on zooplankton abundance, species richness, and community composition. Lastly, data from the second study will provide additional information regarding the increased presence and distribution of the abnormal rotifer, *Keratella cochlearis*.